

Prepared for:

**SHELTER**

# Some Considerations on Water and Climate Change Impacts - St. Louis, Senegal

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## UN-HABITAT / ARCADIS Shelter Initiative

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The *Shelter* Initiative is a partnership between UN-HABITAT and the ARCADIS company which started in March 2010 around a common goal: to improve the quality of life in rapidly growing cities around the world. Through *Shelter*, ARCADIS offers staff expertise on specific technical issues to support UN-HABITAT projects in developing countries.

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L'initiative Shelter est issue d'un partenariat entre l'agence ONU-HABITAT et la compagnie ARCADIS, démarré en mars 2010 autour d'un objectif commun aux deux organisations : l'amélioration de la qualité de vie dans les villes en développement du monde entier. A travers *Shelter*, ARCADIS met à disposition des experts de haut niveau afin d'appuyer les projets mis en œuvre par ONU-HABITAT dans les pays en développement.

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Client Shelter

Title Some considerations on Water and Climate Change Impacts – St. Louis, Senegal

Abstract An experts mission has been organised to St. Louis, Senegal, with the aim to analyse the complex geophysical system and to advise on how ARCADIS could be of further assistance to UN-HABITAT. This report deals with various hydro-morphologic items, which all have a certain relationship with the city's safety against floods from the river and from the ocean. The human settlement side and urban planning perspective are not covered. The general approach of UN-HABITAT is to strengthen local capacity so that local stakeholders can take the lead in addressing their own needs. This report aims to give a modest contribution to that. Conclusions from this report have been presented and discussed during a second mission to St. Louis. The discussions gave new insight and information, which has been integrated in revision nr. 2 of the report.

References Final version of proposed workplan: A2622P1r1, 9 July 2010

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## Executive's summary

ARCADIS and UN-HABITAT, the United Nations Human Settlements Programme, have launched a partnership aimed at improving the quality of life in rapidly growing cities around the world. This partnership is called SHELTER which creates a platform to make the partnership visible and tangible. One of the projects deals with the urban development in St. Louis, Senegal.

The particular location of St. Louis in the estuary of the Senegal River complicates urban planning. Many districts of the town are located on pieces of land (former islands) which are so low that floods take place during periods of extreme water level. The situation is expected to become worse if sea level rise continues and if urban development continues.

The restrictions that the natural system poses on the urban development are not yet fully understood, nor have they been described in a holistic manner. The urban ambitions, however, are large. UN-HABITAT wants to strengthen the local capacity to deal with the "water-dimension" in the urban planning of the city. They have asked ARCADIS to carry out a field mission and to prepare a report in which specifically the flood management aspects are being considered. Because of the technical nature of the mission, reflected in the composition of the team, this report primarily deals with technical matters (coastal and hydraulic engineering).

The following water-related items are considered in this report:

1. The flood risk of the city (Chapter 4);
2. The morphological changes after the new breach (chapter 5);
3. The local coastal erosion (chapter 6); and
4. The poor drainage of rainwater (chapter 7).

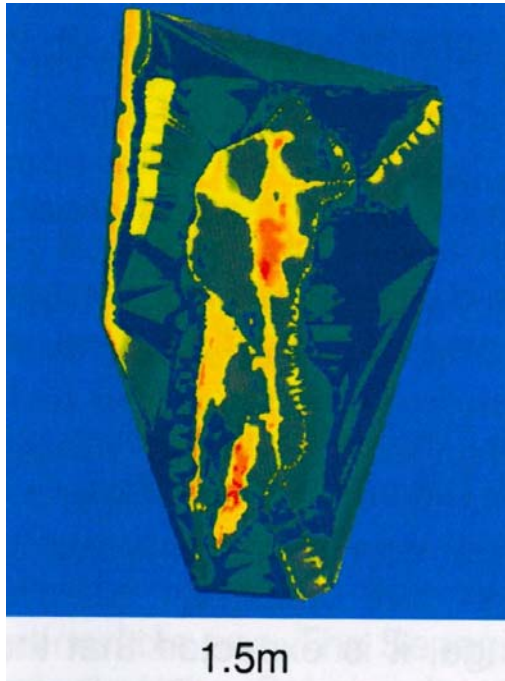
### 1 Flood risk of the city

The extreme water levels with an estimated frequency of occurrence of 1/y is composed of a tidal and a river contribution: tide (MSL+ 0.5) + river (MSL +1 m) = MSL +1.5 m. More extreme river discharges increases the water levels to higher levels. For instance: MSL +2 m happened only once since 1970 (1/40 y). The probability of occurrence increases in the future with rising sea levels. If the above figures are correct, then with a projected 50 cm sea level rise in 2100, the probability of flood increases with a factor 40 in this century.

The average height of the historic centre is MSL +1.5 m. The topography of the island of Sor is a bit more complex. The districts of Ndiolofene and Pikine III (south), have heights up to MSL +3 m. Some other districts like Leona and Diaminar are much lower, with minimum of MSL +1 m.

If the data on extreme water levels are combined with the data on topographic heights, so-called inundation maps can be produced. During periods of "regular" extreme water levels of around MSL +1.5 m, the historic centre just stays dry. At the same time, with an extreme water level of MSL +1.5 m, the lower areas of the island of Sor will be flooded

(see Figure below). In the deeper parts of this island, this may even lead to inundation depths of 0.5 m or slightly more. Such depths do not necessarily have to lead to human casualties, but damage to properties will occur and city life will be disrupted.



*Flooded areas for the extreme water level MSL +1.5 m (from Seck, 2010)*

In a rational risk approach two parameters are considered. One is the probability of occurrence of any flood event; the other is the damage in case such event actually occurs. The actual flood risk is the mathematical product of probability and damage.

The effect of climate change (sea level rise to be specific) increases the flood risk along its "probability axis". However, urban planning and new investments also increase the flood risk along its "consequences-axis". Strategies to control flood risk should address both components of the flood risk equation.

Specific technical measures which can be considered to reduce the probability of a flood are:

- A closed system of robust surrounding dikes, including measures at each cut-through (for instance where a road crosses a dike). To control the groundwater levels in the dike ring area additional measures, such as pumps will need to be considered too;
- Temporary or flexible flood protection measures, such as sand bags, mobile flood walls, or multi-panel barriers; or
- Install flood relieve systems to lower or maximize the water level rise. These systems are activated once a certain critical water level is reached. Further increase in water level rise is reduced if water can either flow into low lying retention basins or flow out to the ocean via an overflow structure across the spit.

Specific measures which can be considered to reduce the damage due to any flood can be:

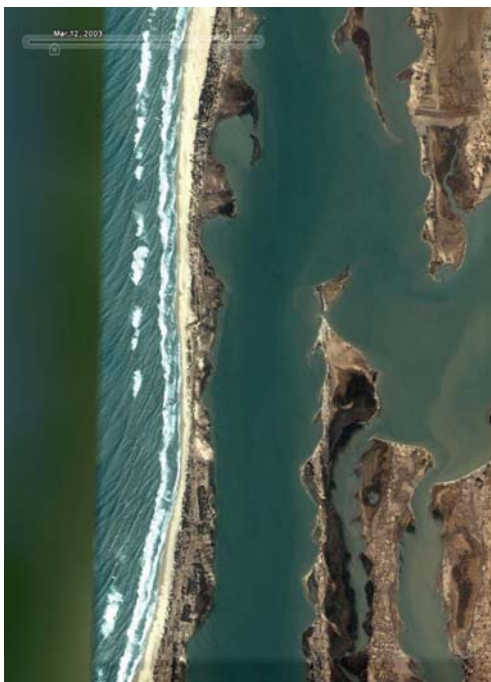
- To build on elevated land;
- To secure evacuation routes and to increase the understanding of people on how to act in times of floods; or
- To design new buildings in such a way that a flood (say up to 0.5 m inundation depth) does not cause any serious damage.

A combination of both types of measures can be considered to develop a more integrated and balanced approach.

## 2. The morphological changes after the new breach

In 2003, heavy rainfall in the drainage basin of the Senegal River alarmed the authorities because it was expected that the water levels at St. Louis would rise above critical levels. It was decided to dig a new outlet for the river water across the spit (the new breach).

The dug channel was about 100 m in length (i.e. the width of the spit at that specific location), some 4 m wide and about 1,5 m deep. It grew rapidly in size in the first days and continued to grow in the following months and years.



### *Before and 1 year after the new breach*

The consequences of the new inlet were:

- The beach in front of Doun Baba Dièye, situated opposite to the new river mouth, eroded rapidly causing the loss of tens of houses.

- The area south of the new river mouth became deprived from fresh water input, which increased the salinity of the water. This part of the former estuary became a lagoon. This was positive for the salt mining in this region, but most likely negative for the ecosystem (incl the mangroves).
- The tide can more easily penetrate into the estuary and reach St. Louis. Mean High Water increased with about 0.3 m.
- Because river water can more easily flow out into the ocean, the rise in water levels due to extreme river discharges became less. This effect is larger than the opposite effect of higher tidal levels, which means that the probability of flooding of St. Louis reduced. (statistical data from before 2003 are therefore no longer useful).

While the new inlet grew in size and migrated in southward direction, at the same time, the old river mouth closed.

The new inlet has reached its maximum size and will only exhibit seasonal fluctuations. It will not erode the spit north of its present location and therefore, will not cause a threat to the city. In fact, the new inlet reduced the probability of occurrence of urban floods, which was the original idea behind digging the channel.

The new inlet migrates further to the south. The expected migration rate is 300 m/y, but this may vary from year to year (200 – 500 m/y). At each new location of the river mouth, similar problems will occur as those experienced at its present location. The shoreline retreat for instance as this has been experienced at Doun Baba Dièye, will also occur in newly exposed areas south of the present inlet. In terms of spatial development it is therefore advised not to locate any new infrastructure in front of the future locations of the inlet.

The ecosystem already suffered from the fact that its former estuarine character (including fresh water input) changed into a lagoon system. But, on top of that, erosion can be expected in the areas that will become directly exposed. This happened many times in the past, and one may argue that nature does not need to be protected against itself. In fact, while the inlet migrates to the south, new estuarine ecosystems will develop north of the inlet, which creates new opportunities for nature conservation in due time.

With a southward migration rate of 300 m/y, one can easily determine when the inlet-related local adaptation can be expected at a certain point.

One option to control the dynamics of the river mouth is the construction of dams on both sides of the inlet (fixation of the river mouth). From an economic and flood risk point of view we don't see any justification for the huge investments that will be required for such an option. Moreover, from a coastal morphology point of view, we recommend to be extremely cautious when considering this option.



### 3 The local coastal erosion

Long-term overall retreat of the coastline is not considered to be very likely. There are, however at least two locations where local erosion already caused damage. One is at the wall at Ndar Toute; the other is at Doun Baba Dièye, in front of the current inlet.

The erosion along the coast at Doun Baba Dieye is expected to continue until a new equilibrium orientation of the coastline has been reached. Such a "static equilibrium bay shape" is reached when the new coastline orientation is perpendicular to the incoming waves. The erosion has probably slowed down already, but some extra coastline retreat may occur. A relatively safe distance zone from the present HW line would be at least 10 m, to avoid any further damage if such ongoing erosion indeed occurs.

Reflected and breaking waves during high tides and storms cause scour in front of the wall at Ndar Toute. This scour can be recognised from the slightly greater depths in front of the seawall (the HW line bends towards the seawall). If the wall was positioned outside the dynamic zone, then no damage would have occurred. To establish a safe distance requires beach morphology studies, but a 20 m set back is probably a reasonable safe first estimate.

Without any quantitative data on the erosion reported for Goxumbaac, it is difficult to make any predictions, but it is likely that more damage will occur under more extreme storm conditions.

### 4 The poor drainage of rainwater

Rainfall stagnation is one of the major flood causes in St. Louis. The bad situation has different causes:

- Low drainage capacity and relatively high groundwater levels of the soil;
- The specific topography of the Island of Sor with lower districts where rainwater collects; and
- The obstruction of surface water streams by structures, such as roads, (low) dikes and other.

The poor drainage problem seems to be most manifest for the Island of Sor. However, high groundwater tables also cause damage to the basements of colonial buildings in the historic centre (Island of Ndar). Possible measures to be considered for the Island of Sor are:

- Create deeper parts in each district where rainwater can be collected and discharged to the surrounding estuary. These lower parts can serve as local squares, parking places, or gardens under less rainy conditions.
- Dig a system of (drainage) canals which may also serve other functions (transport over water, collection and discharge of excessive rainfall, spatial value, etc.). Soil from digging the canals can be used to elevate the land on which new buildings can be planned.

- Adjust the topography in such a way that water is not collected in local depressions anymore, but that it can flow out to the estuary. This includes the upgrade of specific drainage devices to cross the various obstacles.

If water is approached as an opportunity in stead of an enemy that needs to be combated, then St. Louis can make a strong statement to the world, similar as what the Venetians did a long time ago: use the water dimension as a unique selling point and fully integrate it in the short and long term urban planning.

## Sommaire

ARCADIS et ONU-HABITAT, le programme des Nations Unies pour les établissements humains, ont lancé un partenariat visant à améliorer la qualité de vie dans les villes à croissance rapide du monde entier. Ce partenariat, appelé SHELTER (signifiant abris en anglais), crée une plateforme qui rend le partenariat visible et concret. Un de ces projets porte sur le développement urbain à Saint-Louis, au Sénégal.

La situation particulière de Saint-Louis dans l'estuaire du fleuve Sénégal complique la planification urbaine. De nombreux districts de la ville sont situés sur des terrains (anciennes îles), qui sont si bas qu'ils sont inondables pendant les périodes extrêmes de montée des eaux. Il est prévu que la situation s'aggrave si l'élévation du niveau de la mer continue et si le développement urbain se poursuit.

Les restrictions posées par la nature sur le développement urbain ne sont pas encore bien comprises, jusqu'à présent, elles n'ont pas non plus été décrites de manière holistique. Les ambitions urbaines, en revanche, sont grandes. ONU-HABITAT souhaite renforcer les capacités locales afin de faire face à la «dimension eau» dans la planification urbaine de la ville. Ils ont demandé à ARCADIS d'effectuer une mission sur le terrain et de préparer un rapport dans lequel en particulier les aspects de gestion des inondations soient étudiés. En raison de la nature technique de la mission, reflétée dans la composition de l'équipe, ce rapport traite principalement de questions techniques (génie côtier et hydraulique).

Les éléments liés à l'eau suivants sont considérés dans le présent rapport:

1. Le risque d'inondation de la ville (chapitre 4);
2. Les changements morphologiques après la création de la nouvelle brèche (chapitre 5);
3. L'érosion côtière locale (chapitre 6);
4. Le drainage médiocre des eaux de pluie (chapitre 7).

### **Ad 1 Le risque d'inondation de la ville**

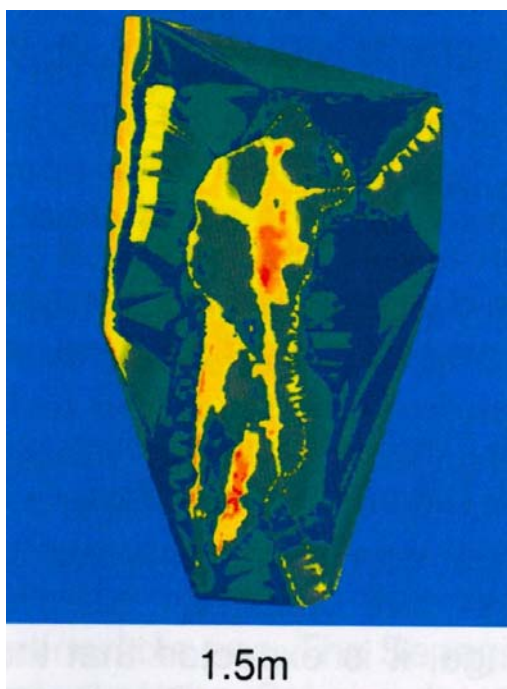
Les niveaux d'eau extrêmes d'une fréquence de survenue estimée à 1/an sont composés du niveau de marée et du niveau des eaux fluviales:

Marée (MSL 0,5), rivière (MSL 1 m) = MSL 1,5 m  
(Soit MSL Medium Sea Level, en français niveau moyen des marées)

Les débits fluviaux plus extrêmes augmentent le niveau d'eau à un degré plus élevé. Par exemple: MSL 2 m ne s'est produit qu'une seule fois depuis 1970 (1 / 40 ans). La probabilité d'occurrence augmentera à l'avenir avec la montée des eaux. Si les chiffres ci-dessus sont corrects, alors une prévision de hausse de 50 cm du niveau de la mer en 2100, augmente la probabilité d'inondations d'un facteur de 40 pour ce siècle.

La hauteur moyenne du centre historique est à MSL 1,5 m. La topographie de l'île de Sor est quant à elle, un peu plus complexe. Les districts de Ndiolofene et Pikine III (sud), ont des hauteurs allant jusqu'à MSL 3 m. Certains autres districts, tels que Leona et Diaminar sont beaucoup plus faibles, avec un minimum de MSL 1 m.

Si les données extrêmes des niveaux d'eau sont combinées avec les données topographiques, des cartes dites d'inondations peuvent être produites. Lors des périodes «régulières» de crues extrêmes de l'ordre de MSL 1,5 m, le centre historique reste relativement sec. En même temps, avec un niveau extrême d'eau de MSL 1,5 m, les zones basses de l'île de Sor sont inondées (Seck, 2010):



Dans les parties plus profondes de cette île, cela peut même conduire à des profondeurs de 0,5 m d'inondation sinon plus. Ces profondeurs ne vont pas nécessairement se conclure en pertes humaines, mais les dégâts aux habitations seront certains, et la vie de la ville sera perturbée.

Selon une théorie de risques relatifs, deux paramètres sont à tenir en compte. Le premier est la probabilité de survenance de tout événement de crue, l'autre est le dommage au cas où tel événement se produise. Le risque d'inondation réel est le produit mathématique des probabilités et des conséquences.

L'effet du changement climatique (hausse du niveau de la mer pour être précis) augmente le risque d'inondation le long de son «axe de probabilités». Toutefois, l'urbanisme et autres projets d'investissements augmentent également le risque d'inondation le long de son «axe de conséquences». Toute stratégie de lutte contre les risques d'inondations devra prendre en compte les deux composantes de l'équation des risques d'inondations.

Des mesures techniques spécifiques peuvent être envisagées pour réduire la probabilité de risques d'inondations, soit par exemple:

- Un système de circuit fermé de digues robustes, y compris des solutions adaptées mises en œuvre à chaque portal (par exemple, où une route croise une digue). Afin de contrôler le niveau des eaux souterraines dans la zone de la digue, des systèmes supplémentaires tels que des pompes devront aussi être considérés;
- Des protections contre les inondations temporaires ou adaptables, telles que des sacs de sable, des murs mobiles d'endiguement, ou des barrières à panneaux multiples;
- Installer des systèmes d'atténuation d'inondations, qui s'activent quand un niveau critique d'eau est atteint. La montée des eaux est ainsi réduite, à mesure que l'eau se déverse dans des bassines de rétention basses ou se déverse dans l'océan par la brèche, aménagée d'une structure de débordement adaptée.

Des mesures spécifiques peuvent être envisagées pour réduire les conséquences dues à toute inondation, soit par exemple:

- Construire où le terrain est élevé;
- Sécuriser les voies d'évacuation, et accroître la compréhension locale sur la façon d'agir face aux crues, ou
- Concevoir de nouveaux bâtiments de telle sorte que les inondations (par exemple jusqu'à 0,5 m d'inondation) ne causent pas de dégâts graves.

Une combinaison de ces deux types de mesures peut être considérée afin de développer une approche durable plus intégrée et équilibrée.

## **Ad 2. Les changements morphologiques après la création de la nouvelle brèche**

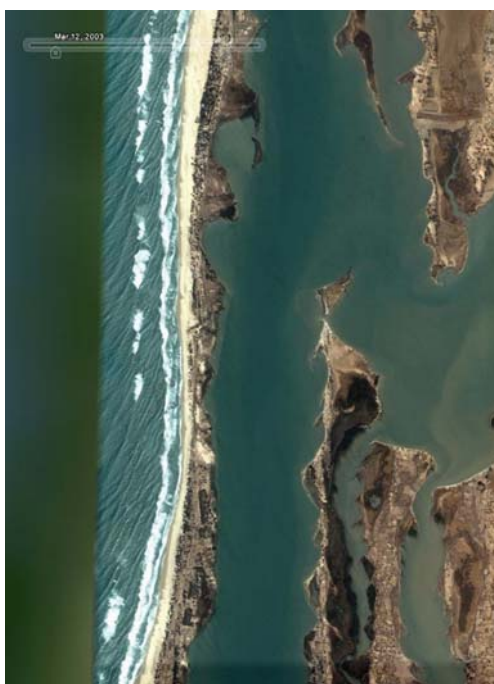
En 2003, de fortes pluies dans le bassin versant du fleuve Sénégal alarmèrent les autorités, car il était prévu que les niveaux d'eau à Saint-Louis s'élèveraient au-dessus des niveaux critiques. Il fut décidé de creuser un canal de délestage (la nouvelle brèche) au travers de la flèche (Langue de Barbarie) pour évacuer les eaux du fleuve.

Le canal d'environ 100 m de longueur (soit de la largeur de la Langue de Barbarie à cet endroit précis), 4 m de large et environ 1,5 m de profondeur fut creusé. Sa taille s'est développée rapidement dans les premiers jours et le canal a continué de croître au court des mois et des années suivantes.

Les conséquences la nouvelle brèche ont été:

- La plage en face de Doun Baba Dièye, située en face de la nouvelle embouchure du fleuve, s'est érodée rapidement, ceci causant la perte de dizaines de maisons.
- La zone située au sud de la nouvelle embouchure du fleuve a été dépourvue d'apports d'eau douce, ce qui a augmenté la salinité de l'eau. Cette partie de l'ancien estuaire est devenu un lagon. Cela a été positif pour l'extraction de sel dans cette région, mais d'un point de vue général, posa plutôt un inconvénient pour l'écosystème (en particulier les mangroves).

- Les marées peuvent plus facilement pénétrer dans l'estuaire et atteindre Saint-Louis. La moyenne du niveau des eaux a augmenté d'environ 0,3 m.
- Puisque les eaux fluviales peuvent plus facilement s'écouler dans l'océan, le niveau d'eau lié aux débits fluviaux extrêmes est devenu moindre. Cet effet est plus important que son opposé, l'effet de la hausse des marées, ce qui signifie que la probabilité d'inondation de Saint-Louis est en fait réduite. (Les données statistiques d'avant 2003 ne sont donc plus utiles).



Alors que la nouvelle brèche s'est agrandie et a migré vers le sud, l'ancienne embouchure du fleuve s'est refermée.

La nouvelle embouchure a atteint sa taille maximale et ne présente plus que des fluctuations saisonnières. Elle n'entamera pas la Langue au nord de son emplacement actuel et, par conséquent, ne causera pas une menace pour la ville. En fait, la nouvelle embouchure réduit la probabilité d'occurrence des inondations en milieu urbain, qui était l'idée originale derrière la création du canal.

La nouvelle embouchure migre plus vers le sud. Le taux de migration est d'environ 300 m/an, mais cela peut varier d'année en année (200 à 5000 m/an). A chaque nouvel emplacement de l'embouchure du fleuve, des problèmes semblables à ceux observés à l'emplacement actuel se produiront. Le recul du rivage, par exemple, comme cela a été expérimenté à Doun Baba Dièye, se produit également dans des zones nouvellement exposées au sud de l'entrée actuelle de l'estuaire. En termes de développement spatial, il est donc préférable de ne pas construire d'infrastructure nouvelle face à tout emplacement futur de l'embouchure.

L'écosystème, qui a déjà souffert du fait de son ancien caractère estuarien (en particulier les apports d'eau douce), est transformé en un système lagunaire. Mais en

deçà, il est attendu que l'érosion se produise dans les régions qui seront directement exposées. Cela s'est produit plusieurs fois dans le passé, et on peut dire que la nature n'a pas besoin d'être protégée contre elle-même. En fait, tandis que l'embouchure migre vers le sud, de nouveaux écosystèmes estuariens se développent au nord, ce qui, en temps voulu, créera de nouvelles possibilités de conservation de la nature.

Avec un taux de migration vers le sud de 300 m / an, on peut facilement déterminer le moment où l'adaptation locale liées à l'embouchure se produira pour tel ou tel endroit.

Une option pour contrôler la dynamique de l'embouchure est la construction de barrages sur les deux côtés de l'entrée (fixation de l'embouchure du fleuve). D'un point de vue économique et risques d'inondations, nous ne voyons aucune justification pour les investissements considérables qui seraient nécessaires. En outre, du point de vue morphologie côtière, nous vous recommandons d'être extrêmement prudents lorsque cette option est envisagée.

### **Ad 3 L'érosion côtière locale**

À long terme et en général, le recul de la côte n'est pas considéré comme très probable. Il existe cependant au moins deux endroits où l'érosion locale a déjà causé des dégâts. L'un est au mur de Ndar, l'autre est à Doun Baba Dièye, en face de l'embouchure actuelle.

L'érosion au long de la côte à Doun Baba Dieye devrait se poursuivre jusqu'à ce qu'un nouvel équilibre de l'orientation de la côte soit atteint. Un tel «équilibre statique de la forme de la baie» sera atteint lorsque l'orientation du nouveau rivage sera perpendiculaire aux vagues. L'érosion a probablement déjà ralenti, mais la côte pourrait encore se retirer plus loin. Une zone de distance de sécurité relative aux présentes HW (High Water, en français Hautes Eaux) serait d'au moins 10 m, afin d'éviter tout dommage supplémentaire si une telle érosion continue vraiment de se produire.

Les vagues de réflexion et de rupture, au cours des grandes marées et des tempêtes, créent désagrégation au mur à Ndar. Cette désagrégation peut être reconnue d'après les profondeurs légèrement plus prononcées en face du mur de mer (la ligne des hautes eaux se dirige vers le mur). Si le mur avait été placé à l'extérieur de la zone dynamique, aucun dommage ne se serait produit. Etablir une distance de sécurité exige des études approfondies de morphologie de la plage, mais en premier lieu 20 m de recul est probablement une estimation raisonnable.

Sans aucune donnée quantitative sur l'érosion rapportée pour Goxumbaac, il est difficile de faire des prédictions, mais il est probable que plus de dégradation se produira en condition de tempête plus extrême.

### **Ad 4 Le drainage médiocre des eaux de pluie**

Le non-écoulement des précipitations est l'une des causes principales des inondations à Saint-Louis. La mauvaise situation a des causes différentes:

- Faible capacité de drainage et niveaux comparatifs élevés des eaux souterraines dans le terrain;
- La topographie particulière de l'île de Sor et ses districts d'altitude plus basse où l'eau de pluie se collecte; et
- L'obstruction des évacuations d'eau de surface par des structures, telles que routes, (petites) digues et autres.

Le problème de drainages médiocres semble être la plus manifeste de l'île de Sor. Cependant, la nappe phréatique élevée est aussi à la source des dommages aux sous-sols de bâtiments coloniaux dans le centre historique (l'île de Ndar). Des solutions à prendre en considération vis-à-vis de l'île de Sor, sont potentiellement:

- Créer des parties plus profondes dans chaque quartier, où l'eau de pluie puisse être recueillie pour être rejetée dans l'estuaire environnant. Ces parties inférieures peuvent servir de places communales, places de stationnement, jardins en dehors des pluies.
- Creuser un système de canaux de délestage qui puissent avoir une utilité multiple (transport sur l'eau, collection et évacuation des pluies excessives, valeur spatiale, etc.) La terre récupérée en creusant ces canaux peut être utilisées pour élever le terrain sur lequel de nouveaux bâtiments peuvent être prévus.
- Adapter la topographie de telle manière que l'eau ne soit plus collectée dans des dépressions localisées, mais qu'elle puisse s'écouler dans l'estuaire. Cela comprend la mise à jour des dispositifs spécifiques de drainage pour passer différents obstacles.

Si le sujet de l'eau est abordé comme une opportunité au lieu d'un ennemi qui doit être combattu, alors Saint-Louis peut faire sa forte déclaration au monde entier, semblable à ce que les Vénitiens ont fait il y a longtemps: utiliser la dimension de l'eau comme un point de vente unique, et l'intégrer complètement dans la planification du milieu urbain à court et à long terme.



# Contents

List of Tables

List of Figures

List of Abbreviations

1	Introduction .....	1
2	Mission report.....	5
2.1	Objective and Programme	5
2.2	Some considerations on scales	6
3	Description of the coastal system .....	8
3.1	Background information	8
3.2	Coastal genesis	13
3.3	Senegal River	21
4	Water levels and land heights .....	25
4.1	Introduction	25
4.2	Situation	26
4.3	Concerns	32
4.4	Possible strategies	32
5	River mouth dynamics .....	35
5.1	Introduction	35
5.2	Situation	35
5.3	Concerns	40
5.4	River mouth fixation	41
6	Coastal erosion .....	44
6.1	Introduction	44
6.2	Situation	44
6.3	Concerns	47
6.4	Possible approaches	47
7	Rainwater .....	50

References

Appendices

A Summary of activities during the mission

B Photo Impression

## List of Tables

- 3.1 Joint probability of occurrence (%) of Highest of sea & swell in the given classes

## List of Figures

- 1.1 Geographical location of St. Louis
  
- 3.1 Computed tidal water level fluctuations off the coast at St. Louis (September 2010)
- 3.2 Annual wind rose off the coast at St. Louis
- 3.3 Annual deep water wave climate (sea and swell) off the coast at St. Louis
- 3.4 Evolution of the coastal area in the last 5,000 years
- 3.4a Historic map of the Senegal River Delta – 1789
- 3.5 Historic positions of the Senegal River mouth (satellite image)
- 3.6 Contours of rainfall for the periods of 1931-1960 and 1961 - 1990
- 3.7 Remaining delta at old river mouth, north of Saint Louis
- 3.8 Elongation of the spit (1983 – 1998)
- 3.9 River discharge rates for the period 1900 – 1965
- 3.10 Distribution of river runoff over the year (period 1900-1965)
  
- 4.1 Water level recordings inside the estuary
- 4.2 Maximum water level rise at St. Louis during extreme river run-off
- 4.3 The districts of St. Louis
- 4.4 Land heights
- 4.5 Flooded areas for the extreme water level MSL +1.5 m
  
- 5.1 Water level changes in the weeks before the new breach was made
- 5.2 Situation before (left) and one year after the opening (right)
- 5.3 Evolution of the old and new inlet

## List of Abbreviations

AFD	Agence Francais de Development
ARD	Agence Regional de Development
ATT	Admiralty Tide tables
CD	Chart Datum (vertical reference level)
DTM	Digital Terrain Model (map of topographic heights)
IPCC	Intergovernmental panel on Climate Change
MLW	Mean Low Water (tide)
MLWN	Mean Low Water Neap
MSL	Mean Sea Level (average water level)
MHW	Mean High Water (tide)
MHWS	Mean High Water Spring
OMVS	Organization pour la Mise en Valeur du Fleuve Senegal

# 1 Introduction

ARCADIS and UN-HABITAT, the United Nations Human Settlements Programme, have launched a partnership aimed at improving the quality of life in rapidly growing cities around the world. This partnership is called SHELTER which creates a platform to make the partnership visible and tangible.

SHELTER focuses on two main activities. The first is the participation of ARCADIS professionals in UN-HABITAT projects, such as for example the recovery program following the Haiti earthquake. The second is the transfer of specialised knowledge through the organisation of seminars and conferences around the world. All these activities aim to support the humanitarian mission of UN-HABITAT.

As towns and cities grow at unprecedented rates, sustainable urbanization is one of the most pressing challenges facing the global community in the 21<sup>st</sup> century. The impact of changing climate changes makes this challenge even more difficult. The general approach of UN-HABITAT is to strengthen the local capacity in such a way that local urban planners and decision makers can better account for the challenges they are facing. An important theme in this respect is adaptation to climate change.

One of the numerous projects carried out by UN-HABITAT deals with the urban development in St. Louis, Senegal. Figure 1.1 shows its geographical position, which is at the coast and on the northern border with Mauretania. The city lies in the estuary of the Senegal River.



Figure 1.1: Geographical location of St. Louis

St. Louis served for a long time as the capital of Senegal and French West Africa (Dakar became capital in 1958). It has always been one of the largest and most active cities in Africa. The historic centre of the town has a World Heritage status. Large scale urbanization took place in the last decades, which led to the situation where thousands of people now live in flood-prone areas. According to Diagne (2007), who bases his conclusion on a 1995-census, the population of St. Louis in 2002 was around 200,000.

The particular location of St. Louis in the estuary of the Senegal River complicates urban planning. The topography of the urbanized area is so low that certain districts can inundate during periods of extreme river runoff. The situation is expected to become worse if sea level rise continues and, as expected, accelerates. The restrictions that the natural system poses on the urban development are not yet fully understood, nor have they been described in a holistic manner. The ambitions to further develop the town, however, are strong.

Under the framework of the "Cities and Climate Change initiative", UN-HABITAT wants to strengthen the local capacity to deal with the "water-dimension" in the urban planning of the city. They have asked ARCADIS to carry out a field mission in which specifically the flood management aspects are being considered and explained to the local stakeholders.

A team of two experts from ARCADIS carried out a field mission from 13 – 18 September 2010. During this mission they collected field data and had discussions with stakeholders at national and local levels. The findings of their mission, including recommendations for further actions, are given in this report. The two experts were:

- Robbert C. Steijn, Director Coasts and Marine Systems, ARCADIS Netherlands – senior coastal engineer and team leader
- Sarah Beesley, project manager, ARCADIS United kingdom – assistant coastal morphologist and interpreter.

Because of the technical nature of the mission, reflected in the composition of the team, this report only deals with technical matters (coastal and hydraulic engineering). Institutional or planning considerations are not considered. The aim of this report is to provide technical information on the physical water-related system of St. Louis and to give recommendations on how this knowledge could be integrated in the activities of UN-HABITAT for St. Louis. The technical data as presented in this report are based on the findings from the mission as well as some results from preliminary desk studies. No (detailed) studies were carried out.

A summary of the field mission is given in Chapter 2. This includes a brief introduction into the time and spatial scales as this proved to be appreciated information during the discussions in St. Louis.

Next, in Chapter 3, a (conceptual) description of the physical system is given. This includes data on hydraulic and coastal parameters, and a holistic description of the evolution and dynamics of the area on different timescales. Chapter 4 describes more specific the fluctuations in water levels relative to the topography of the land.

Chapters 5 till 7 present the findings from the mission and subsequent analysis. Chapter 5 deals in more detail with the dynamics of the river mouth and the possible changes in the near future. It also addresses the question if stabilisation of the inlet would be a wise decision or not. Chapter 6 looks more into the local erosion phenomena in front of the new river mouth and along the fishermen villages of Guet Ndar and Ndar Toute (both located on the spit which separates the estuary from the ocean). Chapter 7 only gives a brief introduction into the poor drainage of rainwater in the urban areas.

The results from the study (as reported in revision nr 1 of this report, dated 6 December 2010) were presented and discussed in two workshops which were held during a second mission from 13 till 18 December 2010. Additional information was collected in the field and some new insights were gained; both have been included in this version 2 of the report (dated 20 January 2011).

It is noted that no detailed studies could be carried out. Conclusions and statements as these are given in this report are based on our best professional judgement only, using impressions from the field mission, results from discussions with other experts and from sources (data and literature) which has been studied.



## 2 Mission report

### 2.1 Objective and Programme

The objective of the first mission (September 2010) was to gather and discuss relevant data and information on the physical behavior of the coastal system (including the estuary), and to understand the current land use and growth modalities of the city, including all current and planned economic activities.

A one-week field mission to St. Louis was carried out by two ARCADIS staff members (Chapter 1) with the aim to become acquainted with the local physical situation. Special attention was given to the area around the new coastal inlet, the fishermen neighborhoods in Guet Ndar, Ndar Toute, and Goxuumbac, the surroundings of the main Island of St. Louis and the existing settlements of Sor (see Figure 4.3 In Chapter 4 for a map of the districts of the city). Discussions were held with local representatives from the municipality and with different involved agencies and organizations as well as with other relevant local and national actors.

The general programme of the first mission was as follows (see Appendix A for a more detailed description of the activities):

- Monday 13 September: Arrival in Dakar; meetings with UN-HABITAT, UNESCO, Red Cross and Red Crescent, Dakar Anta Diop University; transfer by car to St. Louis, arrival in the evening;
- Tuesday 14 September: Meeting with representatives from Municipality, DC, ARD and Gaston Berger University. Rest of the day: field trip to Diama dam and north strip of Langu de Barbarie (hereafter referred to as "the spit");
- Wednesday 15 September: Field trip Saint Louis to Potou. Meetings with the Governor of the Region and ARD;
- Thursday 16 September: Meeting with DC on urban development strategies, collecting data from data center, analysis of collected data, discussions with UN-HABITAT representative, call with AFD, preparing final presentation;
- Friday 17 September: Presenting preliminary findings to local stakeholders. Transfer in the afternoon to Dakar;
- Saturday 18 September: Return flights.

The objective of the second meeting (December 2010) was to present and discuss the conclusions regarding coastal erosion and river mouth dynamics (the "new breach"). These two topics appeared to be of most interest to the local representatives. The general programme of the second mission was as follows:

- Monday 13 December: Arrival in Dakar; transfer by car to St. Louis, discussion with Mrs. Laura Petrella from UN-HABITAT, meeting with Professor Sy from the Gaston Berger University, St. Louis; preparations for tomorrow's presentation.
- Tuesday 14 December: Workshop with representatives from the community, in particular those from the villages Guet Ndar, Ndar Toute, Goxuumbax, and Doun Baba Dieye (the villages that suffer most from the coastal erosion). The workshop was chaired by the mayor of St. Louis.

- Wednesday 15 December: field trip to langue de Barbarie (north of Goxuumbac to north side of the new river mouth). Discussions with local fishermen. Preparations for tomorrow's presentation.
- Thursday 16 December: Presentation about coastal erosion and river mouth dynamics in the plenary session of the International Forum "Changements Climatiques et Gouvernance Locale". Participation in panel discussion at the end of the oral sessions. The forum was attended by approximately 500 persons. Introductory discussions were held with Joseph Guiebo (senior Advisor) and Alioune Badiane (Director), both from UN-HABITAT.
- Friday 17 December: closure meeting with representatives from UN-HABITAT, transfer by car to Dakar, return flights to Amsterdam

We, the ARCADIS team members Rob Steijn and Sarah Beesley, would like to express our gratitude to all who contributed to the success of the mission. Each person who we contacted during the mission showed great willingness to share their thoughts and data with us. They also did it in a very friendly and open atmosphere which made the mission not only successful in terms of data gathering, but also very pleasant.

We would further like to express our sincere gratitude and appreciation to the guidance that we received during both missions from Marie Dariel Scognamillo, Consultant for the Cities and Climate Change Initiative of UN-HABITAT, supporting St. Louis. She arranged for all meetings, and had an important role in the presentation of the results during the second mission.

For a photo impression of the first mission we refer to Appendix B.

## 2.2 Some considerations on scales

When we deal with physical phenomena as well as with human activities, it is important to make a distinction between various scales.

The *spatial* scale is often connected to the dimensions of a problem or coastal feature. For example: the spatial scale of the spit is in the order of tens of km long and hundreds of meters width (so: km<sup>2</sup>). This coincides with the spatial scale of the overall urban development of St. Louis. The estuary itself has a spatial scale of tens to hundreds of km<sup>2</sup>, whereas pools in parts of the town occur on spatial scales of tens or hundreds of square meters (m<sup>2</sup>).

The *time* scale is generally considered as the duration which is needed for certain processes to take place. The time scale with which the new breach developed into a new river mouth (Chapter 5) was in the order of months. The development of the town takes place on a time scale of decades (generations). Accelerated sea level rise also happens on the time scale of generations, but extreme climatic events (droughts and flash floods) occur on time scales of days to months.

Between the various scales, very often, a hierarchy can be recognised. The larger scale-level often provides the boundary conditions (or trends) for developments or processes on a lower scale-level. For example: the coastline retreat in front of the new river mouth



(at Doun Baba Dièye – Chapter 6) is large on the short time scale and under the specific circumstances which were caused by the new river mouth. But, after the river mouth has moved in southern directions (on a long timescale), this localised erosion will stop too.

If the boundary conditions imposed from the larger scale level change, then also the local dynamics changes. The same is true for planning or human settlements. If people tend to move away from rural areas as a result of large scale and long term desertification, this gives an important trend for nearby cities where people move to. Such large scale development (people moving to cities) increases the necessity to accommodate these people, which is basically a problem of local scales and short time horizons.

The “hierarchy of scales” means that if we deal with urban planning for the whole of St. Louis, we have to consider physical phenomena that occur on the same spatial scale. And likewise, if we deal with local issues such as poor drainage of rainwater in certain districts, then we have to consider the physical processes on that scale level.

The hierarchy or rules of scales can also be important if solutions are considered. Solutions are often found at the same scale as the scale of the problem they are supposed to work for. So, if we deal with the problem of global sea level rise, only global solution (CO<sub>2</sub>-reduction) can work. Or, on a local scale: if we want to avoid pools on the streets after heavy rainfall, then solutions on a spatial scale of tens or hundreds of m<sup>2</sup> should be considered (better drainage, cleaning the roads, etc.).

We tried to structure our report by obeying the rules of scales. Chapters 3 and 4 deal with the fluvial, estuarine and coastal system as a whole. This means that we consider time scales of decades to centuries (or more). Chapter 5 deals with the river mouth dynamics, on a spatial scale of 1-10 km<sup>2</sup>, and corresponding time scales of years to decades. Chapters 6 and 7 deal with more localised problems on corresponding short time scales.

## 3 Description of the coastal system

### 3.1 Background information

This Section summarises some hydro-morphologic data which are relevant to better understand the behaviour of the coastal system. The information merely deals with hydrodynamic data like currents, tide, river discharges, wave climates, and some climatic information. The information is retrieved from the following sources:

- Africa Pilot Volume 1;
- Admiralty Tide Tables (ATT) Volume 2;
- Unesco River database;
- Alkyon Hydrobase (wind and waves);
- Various references as listed at the end of this report;
- Various internet sites (Wikipedia and other Google search requests).

#### Ocean currents

The ocean currents off the coast of St. Louis are in general very weak. This location is on the separation zone between the Southwest (SW) - running Canary Current and the Eastgoing Equatorial Countercurrent. During the year the ocean currents off the coast near St. Louis show the following tendencies (in general not very consistent):

- March-May: South-going current with speed of about  $\frac{1}{4}$  knot (i.e. 0.1 m/s);
- June-August: counter clockwise rotation with speed of about  $\frac{1}{4}$  knot;
- September-November: North-going current with speed of about  $\frac{1}{4}$  knot;
- December-February: South-going current with speed of about  $\frac{1}{2}$  knot.

The coastal area near St. Louis can be affected by the phenomenon of upwelling due to the persistent north-eastern trade winds. This may cause temporary rise (decimetres) of coastal waters.

#### Tide (vertical and horizontal)

From the ATT-tables the following characteristics of the vertical tide (water levels) at St. Louis were derived:

- MHWS and MLWS: +1.6m and +0.5 m (spring tidal range 1.1 m);
- MHWN and MLWN: +1.3m and +0.8m (neap tidal range 0.5 m);
- MSL: 1.03 above Chart Datum (CD).

An example of the vertical tidal water fluctuation (for September 2010) is shown in Figure 3.1. Note that these figures are valid for the coast off St. Louis (so not inside the estuary). The water levels have been computed by using the tidal constituents as these are given in the ATT. The tide is semi-diurnal, which means that two high waters and two low waters occur each day. On one particular day, the two successive high waters can differ significantly.

Spring tide (the highest water level changes) occurred around 11 August and two weeks later again. These periods coincide with full and new Moon. Neap tides (with the lowest

tidal fluctuations) occur one week after spring tide. During the field inspections (14-16 September) the tides were average to neap.

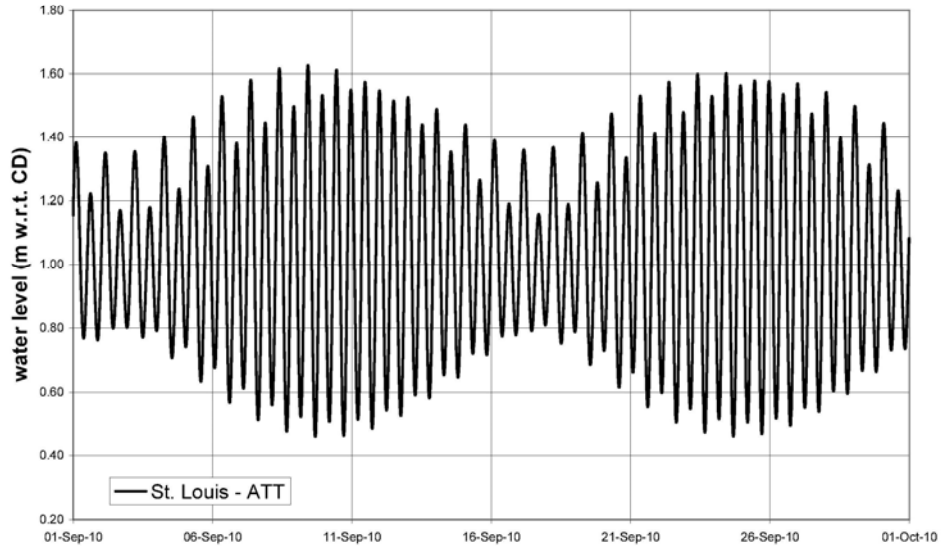


Figure 3.1 Computed tidal water level fluctuations off the coast at St. Louis (September 2010)

The horizontal tide off the coast (tidal flow velocities), away from the river mouth, tend to set North or West during the rising tide (when water levels go up) and South or East on the falling tide, parallel to the coast. These tidal streams are usually very weak and more than a few miles from the coast the tidal streams are negligible.

Near the river mouth, a tidal stream setting towards the estuary occurs when the tide rises (the water levels go up) and setting away from the mouth while water levels go down again. In general, the out-going (so called ebbing) current during the falling tide, is stronger than the in-going current during rising tide. This is because river discharge enhances the ebbing current. Under conditions with high river runoff, during the rainy season, the out-going current (strength and duration) is stronger and longer in duration, than the in-going current.

For the mouth of the Senegal River near St. Louis no specific information on the tidal flow velocities were available to us. However, during the field mission, floating bottles were used to estimate the ebbing flow velocity (standing on the beach on the north side of the mouth). The estimated ebbing flow velocity was around 1 m/s, at some 10-100 m from the shore.

### Wind

The north-eastern trade winds are relatively cool North of 20° N, but south of 20° N these winds bring hot, dry, dusty air from the interior of the African continent. These hot winds, called "Harmattan" are at their greatest extent in January from 10° to 30° N, and

the thick dust haze is carried out to sea to cause navigation problems in places. The average strength of the "Harmattan" is force 3 to 4 Bf in all seasons and gales are rare.

ARCADIS maintains its own world-covering database with ships observations of wind and wave conditions. Based on this database the all year offshore wind climate has been determined for the area between (13.9°N ; -19.3°E) and (18.3°N ; -15.7°E). The results are given in Figure 3.2 (wind rose).

Wind and wave roses provide a quick way of summarizing the directional wave conditions statistics. The number in the centre of the rose represents the percentage of the time that calm conditions occur. The length of an arm of a rose represents the percentage of the time that winds or waves come from the direction that the arm points in (see the bar scale which indicates the percentage represented by unit length). The length of each section of the arm represents the percentage of the time that waves come from that direction and occur in a given height class. The height class is indicated by the width of a section of the arm and its pattern.

It can be noticed from the Figure below that the dominant wind direction is from north to north-east with mean wind speeds in the range of 5 to 8 m/s.

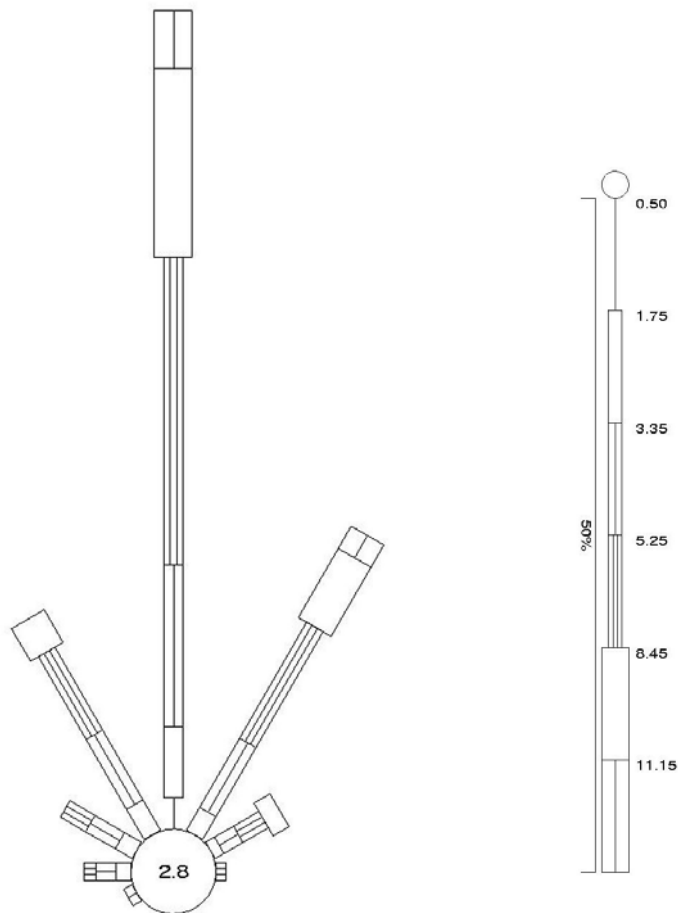


Figure 3.2: Annual wind rose off the coast at St. Louis

### Waves (sea and swell)

The seasonal trade and monsoon winds generate a low swell along most of the coastal waters. The all year highest sea and swell wave heights have been retrieved from our own database for the same area as the offshore wind climate. The results are shown in Figure 3.3 (wave rose) and Table 3.1 (joint probability of occurrence). The dominant wave direction off the coast is from the North to North-East, with mean waves heights in the order of 0.75 m to 1.25 m.

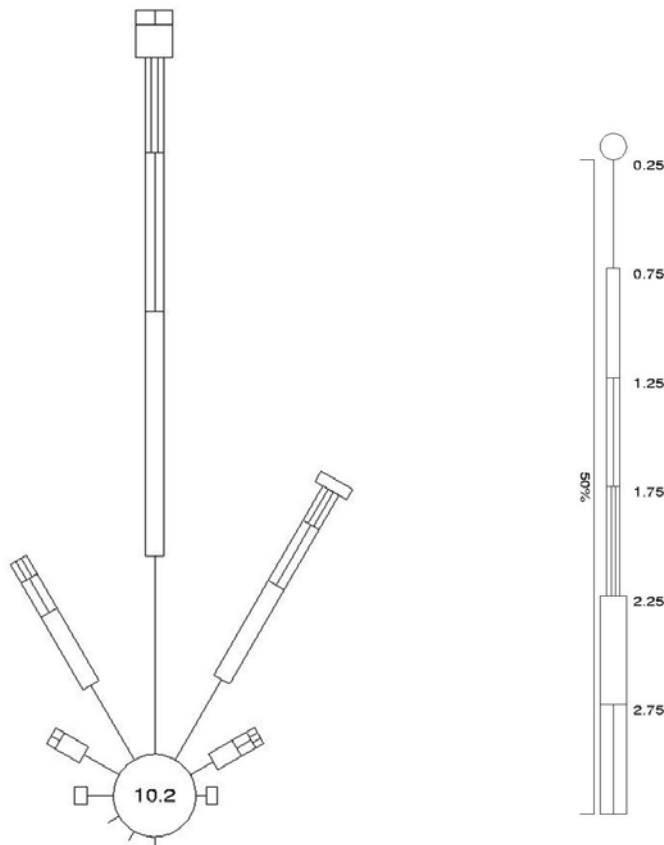


Figure 3.3: Annual deep water wave climate (sea and swell) off the coast at St. Louis

The annual wave energy flux,  $P$ , is the product of wave energy ( $E = \frac{1}{8} \rho g \cdot H_s^2$ ) and wave group celerity. The direction of the energy flux can be computed for each of the above wave direction sectors and then be summed up to obtain the direction of the annual wave energy flux (this is relevant to determine longshore sediment transport capacities – see below). Using all direction sectors from Table 3.1 leads to a direction for  $P$  of  $350^\circ\text{N}$ . In accordance with standard nautical conventions this is the direction from which  $P$  “comes”. If we leave out the direction sector  $-15^\circ\text{N}$  to  $+15^\circ\text{N}$  (these waves can not really reach the coast at St. Louis), the direction of the annual offshore wave energy flux becomes  $313^\circ\text{N}$ . The N direction sector dominates the wind and wave climates.

A line oriented perpendicular to the beach at St. Louis is (in seaward direction) oriented towards  $274^\circ\text{N}$ . This means that the offshore wave energy flux reaches the nearshore zone under a relatively large obliquity (angles of  $39^\circ$  or  $76^\circ$ , depending on whether North is left out or not).

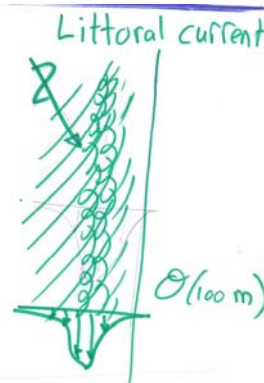
Hs meters		direction degrees													Total
Lower	Upper	-15 to 15	15 to 45	45 to 75	75 to 105	105 to 135	135 to 165	165 to 195	195 to 225	225 to 255	255 to 285	285 to 315	315 to 345		
<	.25	5,75	,93	,30	,18	,07	,11	,32	,20	,20	,46	,60	1,06	10,18	
.25	.75	10,80	5,06	1,44	,59	,23	,30	,53	,58	,69	1,43	2,21	4,71	28,56	
.75	1,25	13,31	5,95	1,47	,57	,15	,16	,29	,32	,34	,68	1,52	4,56	29,31	
1,25	1,75	8,72	3,77	,91	,31	,07	,08	,11	,09	,11	,24	,53	2,15	17,09	
1,75	2,25	5,19	2,18	,50	,17	,03	,03	,06	,05	,11	,24	,18	1,18	9,76	
2,25	2,75	1,77	,65	,18	,07	,01	,01	,01	,02	,01	,02	,06	,30	3,09	
2,75	3,25	,80	,30	,09	,03	,01	,00	,00	,01	,01	,01	,04	,10	1,39	
3,25	4,25	,28	,11	,05	,02	,00	,00	,00	,00	,01	,00	,02	,04	,53	
4,25	5,25	,04	,02	,00	,00	,00	,00	,00	,00	,00	,01	,00	,00	,08	
5,25	6,25	,01	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,02	
6,25	7,25	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	
7,25	8,25	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	
8,25	9,25	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	
9,25	10,25	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	
10,25	11,25	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	
11,25	12,25	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	
12,25	13,25	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	
13,25	14,25	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	
14,25	15,25	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	
15,25	>	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	
Total		46,67	18,97	4,95	1,93	,57	,69	1,29	1,28	1,40	2,95	5,22	14,10	100,00	

Season: All Year  
 Period: 1900 to 2100  
 Location: Hydrobase.net Location (x = -17.75, y = 16.25)  
 Source: Swan computations  
 No. of obs.: 45884  
 Type of data: Highest of sea & swell  
 Tidal phase: undefined level  
 Record: all records

Table 3.1: Joint probability of occurrence (%) of Highest of sea & swell in the given classes

Littoral drift

Waves that approach a shoreline under an oblique angle generate a longshore current (littoral drift). This "coastal river" transports sand particles which are being stirred up from the seabed by the turbulence caused by breaking waves (see sketch below).



For an understanding of the coastline behaviour, it is important to quantify the longshore sand transport capacity. We have used a computer model to make these calculations (UNIBEST). It is noted that we did not have any data on particles grain size, so we made our own estimates based on the field survey. For the average grain size we used in the computations:  $D_{50} = 200 \mu\text{m}$ .

The computed (integrated) annual longshore transport rates are as follows:

- To the North: 15,000  $\text{m}^3/\text{y}$
- To the South: 190,000  $\text{m}^3/\text{y}$
- Resultant to the South: 175,000  $\text{m}^3/\text{y}$  (this becomes 115,000  $\text{m}^3/\text{y}$  if we use  $D_{50} = 300 \mu\text{m}$ )

The highest rate of longshore transport was computed at a depth of about MSL -2 m; this becomes negligible at depths greater than MSL -6 m.

### Climate

The hot humid weather with monsoon rains persists most of the year near the Equator. Farther North, from about 5° to 18° N (note St. Louis lies at about 16° N), the length of the wet season is progressively less, and is governed by the extent which the Inter Tropical Convergence Zone moves to the North. There is little sign of a wet season on the African coast N of about 18° N. The average sea surface temperatures near St. Louis are as follows:

- February: 18 to 19 °C
- May: 20 to 21 °C
- August: 26 to 27 °C
- November: 24 to 25 °C

## 3.2 Coastal genesis

### Historical large-scale geological development

The Senegal River delta has a long and interesting history with respect to its geo-genesis. When considering the Senegal and Mauritanian coast at a large scale, the contours of a historic river delta can be observed. Saint Louis is situated at the southern end of this delta.

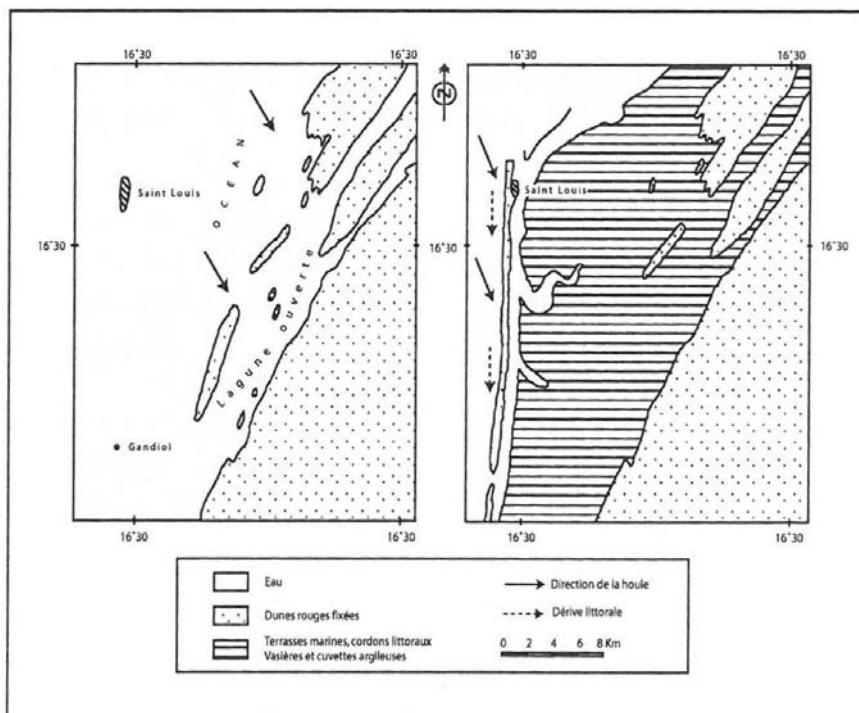


Figure 3.4: Evolution of the coastal area in the last 5,000 years [source: Sy, 2009]

The Senegal River delta has evolved over thousands of years. Figure 3.4 shows the area near Saint Louis some 5,000 years ago (on the left) as well as the current situation (on

the right). As it can be seen, 5.000 years ago, the Island of Ndar (with its today's historic centre) was situated approximately 15 km into the sea. The Senegal River debouched at that time into the ocean via several more northerly river mouths. Gradually, the ancient delta built out with fluvial deposits.

Over thousands of years, the Senegal river built out a typical "stunted" delta, which is visible in the 200<sup>+</sup> -years old map shown in Figure 3.4a (by T. Jefferys, a British Geographer). This is a type of delta with significant marine influences. The shape of the delta coastline on the 1789 map is rounded, which is somewhat less the case for today's coastline. Without any new fluvial deposits from the river, the whole delta is bound to disappear by the eroding marine forces, but this process generally occurs on a geological timescale (thousands of years). If we compare the coastline from 1789 with that of today (see Figure 3.5), then it can not be concluded that the delta – as a whole – is rapidly disappearing.



Figure 3.4a Historic map of the Senegal River Delta – 1789

During the last centuries, the location of the river mouth has significantly moved southwards. The four red arrows in Figure 3.5 below (source: Google earth), indicates the locations of ancient river mouths (now closed). The only mouth of the Senegal River is now situated south of the city of St. Louis.

Around 1850, the river mouth shifted from north of St. Louis to south of Saint Louis. At the same time, the spit (Langue de Barbarie) extended further to the south. In between



1850 and 1900, the spit grew by 15-16 km, which gives an average migration rate of 300 m/y.

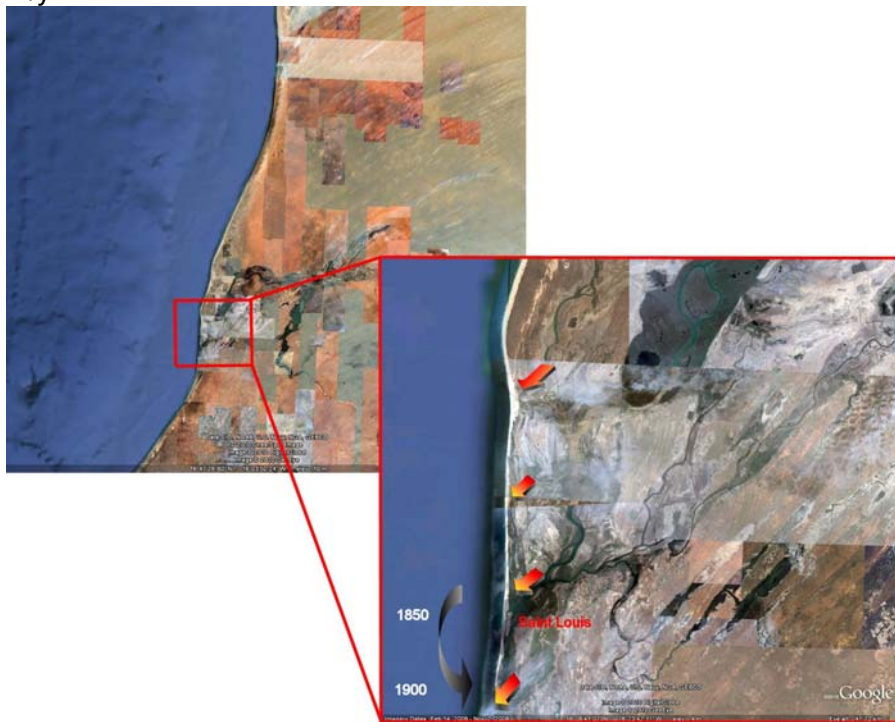


Figure 3.5: Historic positions of the Senegal River mouth (satellite image)

In the last few centuries, the dynamics of the Senegal River changed a lot. As it can be seen from Figure 3.6, rainfall contours (in terms of mm/y) are gradually moving in southward direction. This means that Senegal is actually becoming dryer.

In 1985, the Diama Dam was built (also see Section 3.3), which also altered the hydraulic regime of the Senegal River. In Barousseau, et al. (1998) the impact of the construction of the Diama dam on the Senegal River estuary is described. Based on several measurements, they concluded that:

- The river mouth migrated in southward direction with 2.8 km in 5 years, which is 560 m/y on average. Since migration velocity of a river mouth depends not so much on the hydraulic regime of the river (but on the littoral transport in stead), it can not be explained why this figure is almost twice the figure mentioned above;
- Sediment input from the river into the estuary and the coast did not occur (data on the situation before the dam however could not be found).



Figure 3.6: Contours of rainfall for the periods of 1931-1960 and 1961 - 1990 [source: <http://www.cartographie.ird.fr>]

The delta of the Senegal River Delta, which lies for most part in Mauretania with the spit along its most southern fringe, seems to be formed in the last 5,000 years. The delta has been built up primarily with sediments being delivered by the Senegal River. In the last centuries, the river mouth has shifted to the south and the sand discharge reduced possibly because of lower water discharges (reduced precipitation rates in the river's drainage basin). Today, the Senegal River doesn't bring sand anymore to the delta. The various dams play an important role in that respect. Wave-induced and other marine currents now redistribute the sand along the coast, leading to a re-shape of the old delta. This re-distribution of the old delta sand deposits, leads to erosion at the locations where old river branches debouched into the sea (i.e. where the delta front progressed the farthest). The southward migration of the spit is caused by sand which is transported from these eroding areas to the south (littoral drift – Section 3.1).

On the basis of the still apparent delta-shape (see Figure 3.7), we expect that the spit will continue to receive sand from these old sand deposits for at least the next 50 - 100 years. It is likely that due to accelerated sea level rise, the whole coast will undergo a system shift anyhow before the sand supply from the old delta stops.

Below in Figure 3.7, the coastal area north of St. Louis is shown. A straight line is drawn parallel to the coastline at Saint Louis. As it can be seen, the coastline just north of St. Louis is not straight. The contours of the old delta can still be observed with the spit on the southern fringe of it.



Figure 3.7: Remaining delta at old river mouth, north of Saint Louis [Photo: Google Earth]

### Existing local coastal morphological system near Saint Louis

Around 1850, the spit (Langue de Barbarie) was created after the river mouth shifted from just north to just south of Saint Louis. The spit develops in southern direction with a propagation speed in the order of 300 to 500 m/y. Figure 3.8 shows the growth of the spit from 1983 till 1998 (source: Ibrahima Diop). The average migration velocity of the river mouth in this period was according to this map ca. 500 m/y (7 km in 15 years time). The maximum length of the spit was about 28 km.

### Carte de l'estuaire et de l'embouchure du fleuve Sénégal

Réalisée à partir de la carte au 1:50.000 produite en 1992 par le Gouvernement du Sénégal avec l'aide de l'Agence Japonaise de Coopération Internationale (JICA)



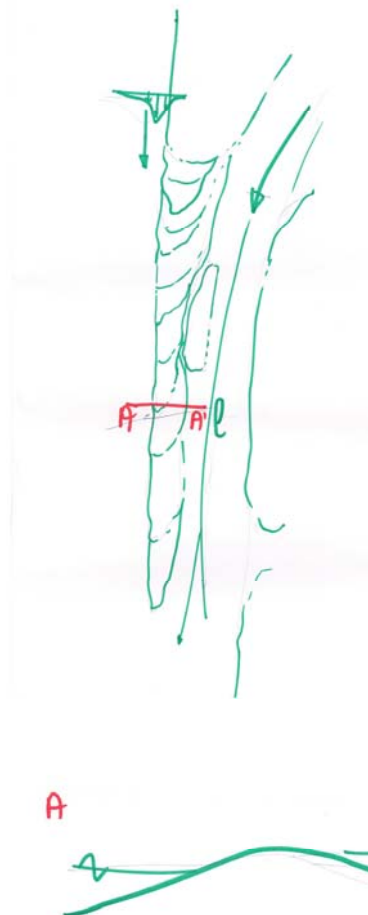
Figure 3.8 Elongation of the spit (1983 – 1998) according to I. Diop.

A quick check on these growth rates can be made by using the computed longshore transport rates (175,000 m<sup>3</sup>/y – see Section 3.1). We assume a width of the spit of 100 m and a profile height of 7 m (from MSL -5 m till MSL +2 m). If the spit grows with 300 m/y, a total littoral sand input of 210,000 m<sup>3</sup>/y would be required. This figure largely

corresponds with the computed transport capacity ( $175,000 \text{ m}^3/\text{y}$ ), which shows that  $300 \text{ m/y}$  is perhaps more likely than  $500 \text{ m/y}$  (or more).

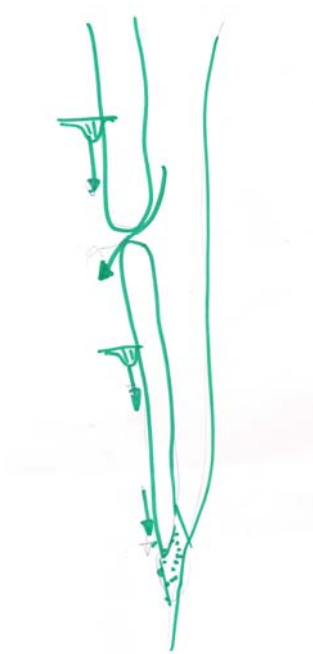
With an increasing spit length, also the length of the river increases, which results in increased river water levels near Saint Louis (otherwise the water from the river can not effectively flow out).

Once the difference in water levels across the spit becomes too large, the spit breaches (see sketch below). Since 1850, 19 breaches have been recorded. Not all of them were however significant; some of them closed shortly after and did not develop into a new stable river mouth.



In case of a significant breach, a new river mouth is formed at the most northern section of the spit (near St. Louis). In such a situation, two river mouths exist of which the most northern mouth discharges all the river run-off. At the southern river mouth, the longshore transport of sediment remains the same, while the flow (tide and river) through the mouth is now greatly reduced. Consequently, the southern river mouth will be closed with sand input from the northern shoreline (see sketch below).

At the north side of the northern river mouth, a spit will again form and the river mouth is gradually "pushed" to the south again. This natural cycle repeats itself with a period in the order of a few decades. Breaks of the spit have occurred frequently in the past during periods of high river floods or during periods of long-lasting oceanic storms.



### Washovers

Ocean waves that break on the beach cause a beach-upward flow, called the wave run-up (in  $m^3/m/s$ ). This flow of water reaches higher levels of the beach when the average water level is high, when the waves are high, or especially if both are high. Under specific storm conditions it is possible that water flushes even over the top of the Langu de Barbarie. Such phenomenon is called a washover.

Local fishermen mentioned that during heavy storms, indeed water runs through their (lowest) streets from the seaside towards the estuary. It was also mentioned that the Langu de Barbarie has experienced several breakthroughs in the past, which closed immediately after the events. Such "breakthroughs" cannot be compared with the breaches from inside, which generally stay open and lead to a new river mouth. The "breaches" which occur during a washover generally have not enough scouring capacity to make a stable breach. A breach from the riverside, however, is caused by vast amounts of flowing water with generally huge scouring capacities. This is why a breach from the riverside (fortunately happening only if the hydraulic gradients is large enough: see above), can lead to a new river mouth, whereas breaches from the seaside (by washovers) will all soon close again.

Washovers can lead to a gradual landward movement of the sand spit, so towards the river. For a fixed location, such as the front row of houses in the three fishermen villages, this gradual movement in fact will be experienced as erosion. After all: the beach in front of the villages reduces in width and the sea gets nearer to the houses. However, this phenomenon is not so much erosion in terms of losses of sand, but a relative movement of the spit as a whole. Erosion on a larger scale is not very likely because of the sand deposits from the old delta which are still feeding the coast. But washovers can indeed, if they frequently occur at many places, lead to erosion-like coastal problems. Inspection of the coastline on the riverside of the Langu de Barbarie did not show clear signs of washover fans. These are fan-shaped deposits of sand which can sometimes be

found on the bayward side of a historic washover event. So, the general feeling is that washovers will not lead to a *rapid* landward movement of the langue de Barbarie.

We did find one particular place where washovers probably have caused landward transport of sand across the spit: just north of the fishermen village Goxuumbac. The height of the Langue de Barbarie is here much lower (visually estimated to be not much more than 3 m above MSL). The photo below was taken during the second field mission on 15 December 2010 at this location (looking northward, towards Mauretania). The camera looks a bit into the estuary. Sand deposits have covered the original vegetation. A narrow strip of garbage was found, which nicely borders the extent of the (last) washover fan. The width of this washover mouth was estimated to be around 200-300 m. The volume of sand inside the washover fan is difficult to estimate, but if we assume a surface area of 30.000 m<sup>2</sup> (300 m \* 100 m) and a layer thickness of 1 m, then the volume could be as much as 30.000 m<sup>3</sup>.

The height of the washover mouth is estimated to be at least 1 or 2 m below street level of Goxuumbac. Since it has been reported that under storm conditions water flows through the streets of Goxuumbac, this means that the washover will surely be activated.

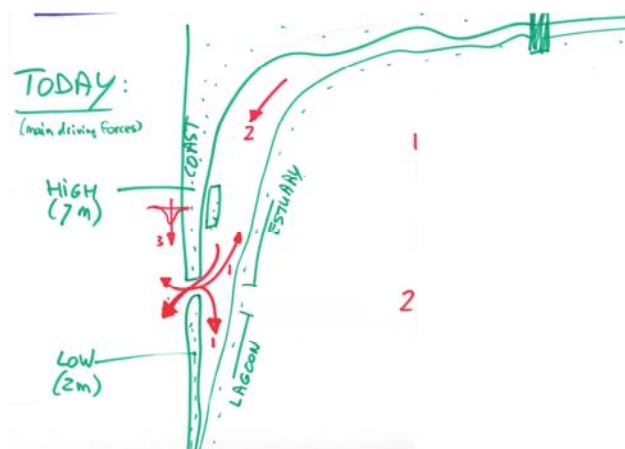


The effect of this washover fan on the longer term is that it causes beach erosion. It is a kind of "sand sink". Let us assume that the above 30.000 m<sup>3</sup> was deposited in a period of ten years, then a yearly total loss of 3.000 m<sup>3</sup> occurred. Such sand loss will be distributed along a certain stretch of coastline (due to the impact of waves and currents), let us assume a distance of 3 km. Under these very rough assumptions, this could explain a beach retreat of about 1 m/y, which is significant.

### Lagoon or Estuary

The sketch below shows the different flow mechanisms after the creation of a new river mouth (either natural or manmade as described in Chapter 5). The tidal filling and emptying generates tidal currents (indicated with 1). The river flow (indicated with 2) goes straight from the Diama dam to the river mouth and into the ocean. Along the beach, breaking waves generate a longshore flow (littoral drift), indicated with 3 (explained in Section 3.1).

The system north of the river mouth receives fresh water from the river and salt water from the tides; this part of the system is called an estuary. The southern part of the basin does no longer receive fresh water from the river and therefore becomes completely salt. This part is called a lagoon.



Salt mining in what we now refer to as the lagoon is one of the economic activities. The salt production indeed increased after 2003 when a new river mouth was formed (Chapter 5). The negative consequence of a system shift from estuary to lagoon, is that nature has to adapt too. Mangroves and other ecological values will suffer from it, although it can be argued that this happened in the past several times and that this can be regarded as just natural fluctuations.

### 3.3 Senegal River

The Senegal River drains a catchment area of some 300,000 km<sup>2</sup>. One of its main tributaries (Bahfing) originates from mountains in the republic of Guinea. The other main tributary (Bahkoye) originates from the Siguiri basin and incises a plateau in Mali. On its way down, the river receives input from numerous smaller tributaries, which all rise in humid tropical regions. The hydrologic regime of the river is therefore determined by the rainfalls in the upper regions and not by the semi-arid and arid regions through which it flows before reaching the Atlantic Ocean. Currently, all river water reaches the ocean at St. Louis.

Information of the river discharge is derived from the UNESCO database of river runoff. This database contains yearly values of maximum, minimum and mean discharge and monthly values for again maximum, minimum and mean discharge. Figures 3.9 and 3.10 present the mentioned yearly and monthly values for the station Dagana. This station is

located about 120 km upstream of the Diama Dam which in turn is about 40 km upstream of St. Louis.

Figure 3.9 indicates that the highest discharges occur in the months from August to November. Very low discharges can be observed during the months from January to June. The highest observed discharge is about 3,300 m<sup>3</sup>/s, whereas 2,300 m<sup>3</sup>/s represents the mean high values.

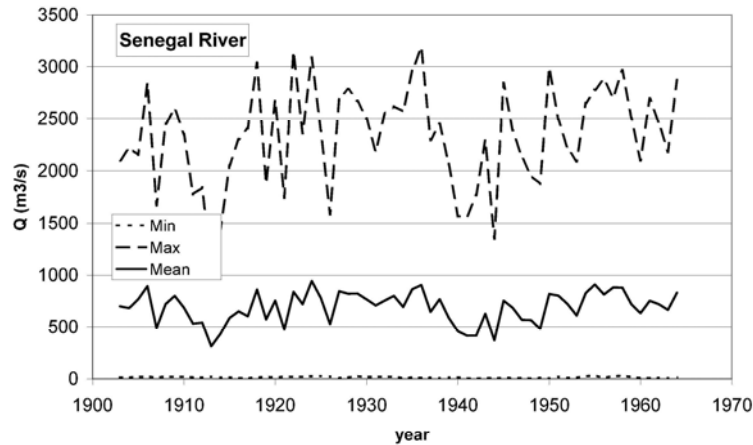


Figure 3.9. River discharge rates for the period 1900 – 1965

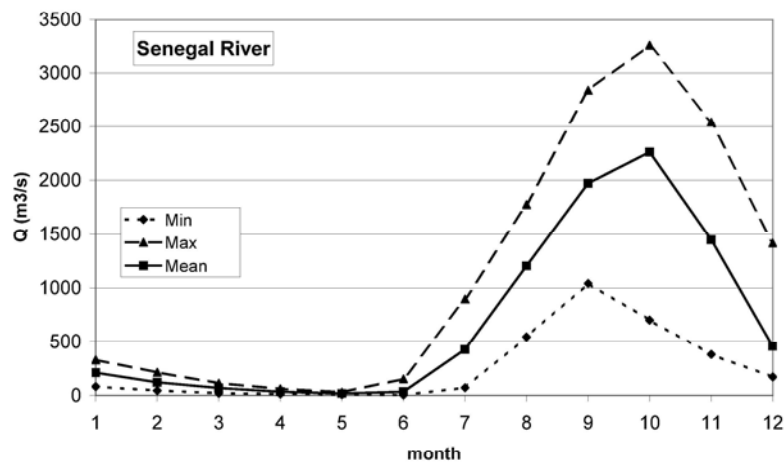


Figure 3.10. Distribution of river runoff over the year (period 1900-1965)

### Senegal River Development Organisation (OMVS)

The OMVS was constituted in 1972. Its predecessors already had a century-long history of attempts to develop the hydraulic potential of the Senegal River. Five Member States co-



operate within OMVS and make strategic joint decisions to manage the hydraulic regime of the river.

The OMVS has five strategic challenges (OMVS, 2002), namely:

- Food security for the people living in the basin area;
- Preservation of the equilibrium of ecosystems;
- Reduction of vulnerability of the Member States' economies for climatic uncertainties and extremes;
- Securing and improving the income of people living in the basin area;
- Acceleration of the Member States' economies.

The development of navigable routes and port infrastructures are part of the OMVS' strategy.

A number of dams have been constructed to control the river regime. Some of these dams have been constructed to generate electricity, others serve other goals as well. The Diama Dam for instance, was built to stop salt water from entering the lower parts of the river. In this way agriculture, regeneration of a vegetal cover in the humid zones and improvement of potable water supply improved. The Diama dam is also the downstream limit of the managed basin area for the OMVS and the upstream limit of the estuary.



## 4 Water levels and land heights

### 4.1 Introduction

The main characteristic of the city of St. Louis is that it is surrounded by water (the city was built on three islands). The ground water table is shallow and the area is relatively low compared to sea level. The water levels around the city vary at different time scales (hours to decades) due to:

- Ocean. Coastal upwelling can occasionally occur which may rise the average sea water levels with cm's to dm's. Such large scale rise in sea levels will also be felt inside the estuary and lagoon, and so in the waters surrounding the city. The area is not susceptible to low-pressure fields or hurricanes, which in some other places in the world could raise the water levels with 0.5 to 1 m for several days.
- Tide. Once the water on the seaside of the inlet starts to rise, a water level gradient directing towards the inlet starts to develop. At a certain point in time, this leads to an inflow of ocean water into the estuary (towards the city) and into the lagoon (towards the south). Water levels will then start to rise. Water levels in the estuary fall again once the water levels outside the river mouth become low enough. The penetration of the ocean tide into the estuary depends on water depth, geometry, tidal constituents of the ocean tide and the distance to the inlet. After the new river mouth developed, which is described in Chapter 5, this distance abruptly became smaller, resulting in a sudden increase in tidal water level variations (higher High Waters and lower Low Waters). The tide could more "easily" reach the city.
- River discharge. The volume of water which passes the Diama dam flows through the estuary and debouches into the ocean through the river mouth. River water does not reach the lagoon south of the river mouth and therefore has no effect on the water levels in that part of the system. If the river discharge through the Diama dam is high, water levels will rise because of the increasing runoff capacity of the estuary. This runoff capacity is a function of distance, average depth, geometry, discharge characteristics, but also of the distance between the dam and the inlet. This distance became smaller after the new river mouth developed and as a consequence of that, the rise of water due to high river discharges became smaller. It became "easier" for the river water to flow out.

There are no other physical phenomena (such as groundwater, precipitation, drainage, etc.) that influence the water levels around the city noticeably. On the long term however (decades), sea level rise will increase the water levels too. As long as the whole coastal system doesn't change drastically (such as the loss of the spit leading to an open coast in stead of an estuary), the water level variations are 'just' raised with the actual sea level rise. As mentioned in Section 3.2, we don't foresee such a drastic systems shift in the next 50-100 years.

Fluctuating water levels are by itself not a problem; accept when the water level exceeds the heights of the land. Without any protection, such as dikes or water retaining walls, the area will then be flooded. This has happened to St. Louis in the past, which initiated the construction of various low dikes and walls. These structures however did not seem

to be robust nor closed in the sense that the measures surround a certain piece of land completely. To understand the potential threat of flooding by water levels exceeding the topographic heights, it is important to know both the water levels and the land heights. In this Chapter relevant data is presented for which we largely used data collected during the field mission and the information as presented in the M.Sc. thesis of Mr. Amadou Seck, a former inhabitant of St. Louis who did his Masters on flood management at UNESCO-IHE in Delft, The Netherlands.

## 4.2 Situation

### Changing water levels

The relative sea level rise is the combined effect of local land subsidence and the eustatic rise of the ocean levels. Although data on land subsidence are unknown to us, we don't expect that this contributes much to the local relative sea level rise. If land subsidence can indeed be neglected, we can focus on the eustatic sea level rise (hereafter referred to as sea level rise).

Since the end of the last Ice Age, sea levels have been rising. The current sea level rise has occurred at a mean rate of 18 cm for the past century. Based on recent satellite observations this rate has accelerated, and the general expectation is that an increased sea level rise will occur in the next century as a consequence of the global greenhouse effect. Different prediction models give different forecasts for the sea level rise in the next century. This is true for the global sea level rise, but also for local sea level rises such as for the coast of St. Louis. In spite of huge scientific efforts, there is a lot of uncertainty involved. It can however, not be excluded that for the coast of Senegal, a sea level rise of 1 m in the next century occurs. But lower (and even higher) figures are possible too. In its fourth Publication, the IPCC expects a global sea level rise between 20 and 85 cm for the next century (50 cm until 2100 on average).

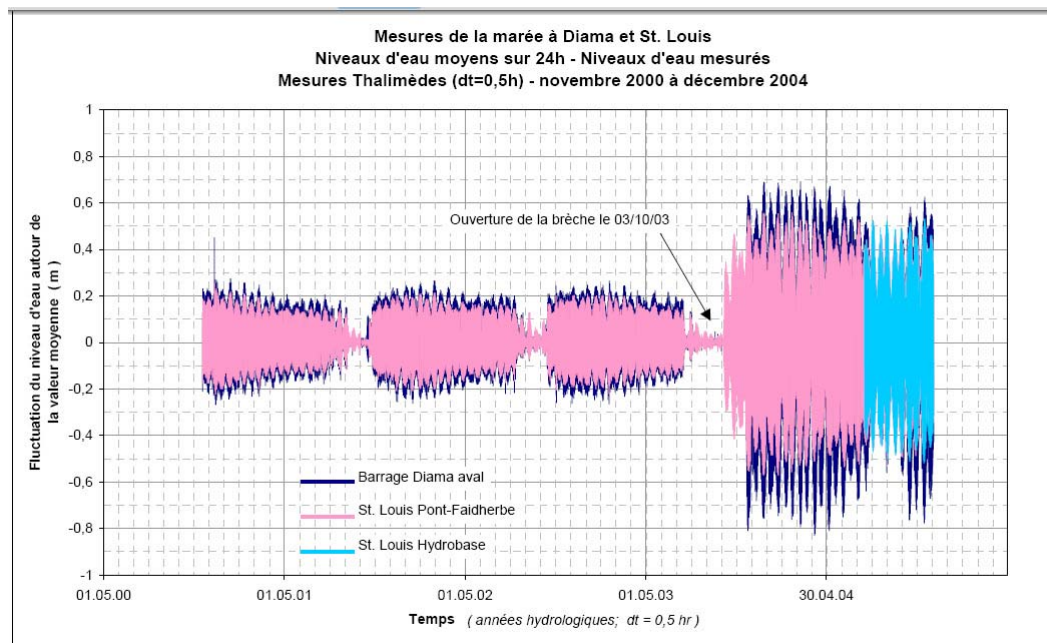


Figure 6 : Amplitude de la marée à Diama et Saint-Louis de nov. 2000 à déc. 2004

Figure 4.1. Water level recordings inside the estuary (from Seck, OMVS data)

The computed offshore vertical tidal fluctuations at St. Louis are shown in Figure 3.1. The measured water levels at St. Louis and Diama for the period August 2000 till August 2004 are shown in Figure 4.1. This Figure has been obtained from Seck (2010), who refers to OMVS as source. The average recorded high and low water is around MSL+0.2 m and MSL -0.2 m, respectively for the first three years (we have assumed that the reference level coincides with MSL).

The tidal range (on average some 0.4 m) at Pont Faidherbe is much lower than offshore because the tidal range reduces when the tide penetrates into the estuary. In front of the Diama dam, the tidal range increases slightly again for unknown reasons (perhaps due to reflection).

Tidal water level fluctuations increased after the new breach in 2003. The average high water increased to MSL + 0.5 m, and the average low water levels to MSL – 0.6 m. These figures correspond reasonably with Mean High Water according to the data presented in Section 3.1 (MSL +0.45 m). There is a discrepancy in the measured and computed low water level, but this is less relevant for flood risk assessments. The lesson which can be teased out from this observation is that the penetration of the tide from the new river mouth to the city has become much "easier" (less flow resistance), leading to an increase in tidal water levels fluctuations.

During the wet season, water levels may also rise when the discharge figures from the Senegal river increase. The wet season starts in July / August and ends in October / November. This means a steady increase in river discharge during the wet period and a steady decrease during the other (dry) period (Section 3.1).

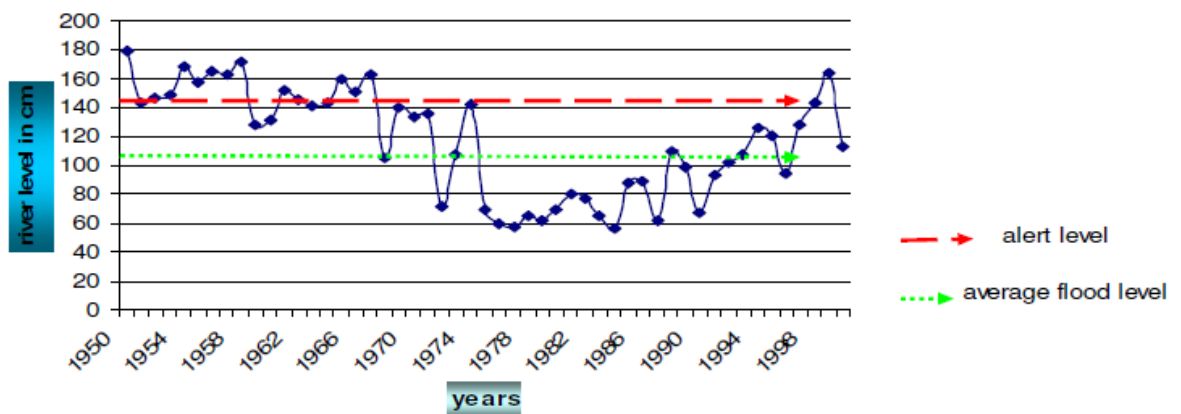


Figure 4.2. Peak discharge levels at St. Louis during extreme river run-off (obtained from Seck, 2010)

Seck (2010) presents a plot with the measured maximum river discharge levels at St. Louis (Figure 4.2). The coordinates of the measuring point and the vertical reference level are unknown. If we assume that each dot shows the measured water level at St. Louis at the moment that the discharge through the Diama dam during the wet season was at its maximum, and that tidal effects can be ignored (the tidal ranges were smaller than 0.4 m before 2003 anyhow), then the plot gives important information about extreme water levels due to river run-off.

The discharge rates at the Diama dam are computed by using a formula in which the measured water levels on both sides of the barrier are used. So, assumably, the dots represents the moments per year where the head difference over the dam was at its maximum. We further assume that zero-level corresponds to MSL.

Figure 4.2 shows the droughts that afflicted the Sahel Countries in the Seventies and Eighties. The average increase in water level is around 1 m (green line), but levels of +1.4 m have occurred more than once.

High river discharges generally last for more than a few days. This implies that when the water levels are raised by high river discharges, at least one tidal cycle will occur. Being statistically independent parameters, tidal water levels and river water levels can be superimposed, meaning that both high waters must be summed up. If the peak river discharge occurs for more than one week (data are not available, but it seems realistic), then spring tidal data need to be used.

#### Extreme water levels summarised

Extreme water levels that which be expected at least once a year: tide (MSL+ 0.5) + river (MSL +1 m) = MSL +1.5 m.

More extreme river discharges (which happened only once since 1970- see Figure 4.2) increases the water levels to MSL +2 m.

Both figures will rise in the future with rising sea levels.

#### The city

Four distinctive urban zones can be distinguished:

1. The spit area (called "Langue de Barbarie"), which is a few hundred meters wide strip of land in between the ocean and the estuary. There are three districts called Guet Ndar, Ndar Toute and Goxumbaac. Altogether some one quarter of the total population lives in these districts (approximately 40,000 people, mainly fishermen and their families).
2. The historic centre of St. Louis (also called the "Island of Ndar"), which is a UNESCO world heritage and because of its unique French colonial architecture the most popular area for tourists.
3. The larger island of Sor with its many districts. This part of the city nowadays houses the biggest portion of the total population and has the highest growth rates. The most recent new developments take place in the southern districts called "Pikine".
4. The outer regions further inland, which are hardly developed yet.

The different districts of St. Louis are shown in Figure 4.3 below

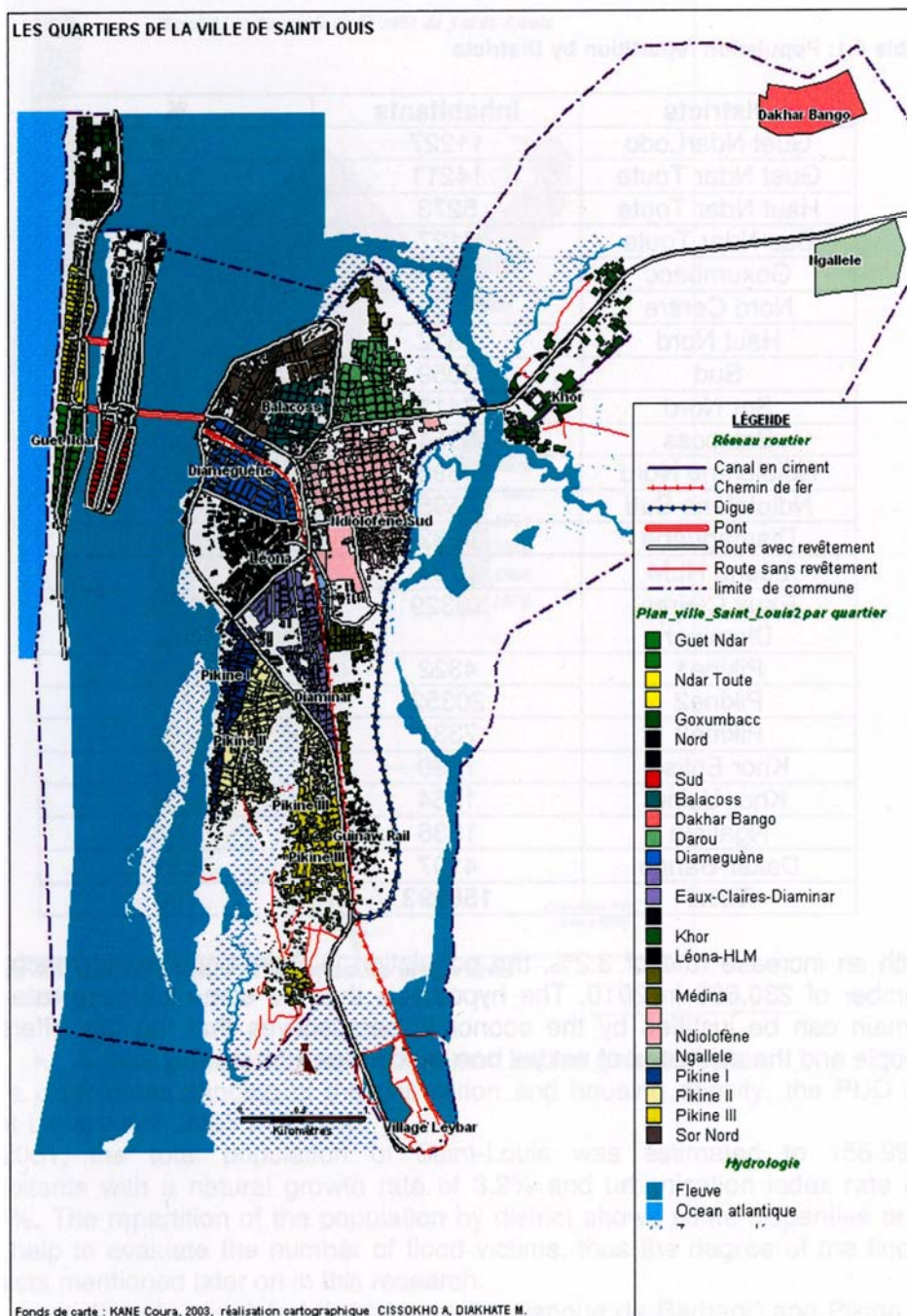


Figure 4.3 The districts of St. Louis (copied from Seck, 2010)

### The land heights

Land is flooded if the local water level exceeds the local topographic height (in case of no flood protection). During the mission it turned out to be not very easy to find a map with reliable data on land heights. Three old maps (dated 1972) could be retrieved with printed data on local land heights ("Carte du bassin du Senegal", maps 1/50,000); these maps also seemed to exist on microfiche (but this could not be verified by lack of equipment to read the microfiches).

Seck (2010), however, presents a Digital terrain Model (DTM) with detailed topographic heights of the city and its surroundings (see Figure 4.4 below). It could not be determined which data formed the basis for this map.

We assume that the zero-reference level on this map coincides with MSL. It is noted that the map shows heights; not depths. In reality the depths of the “wet parts of the map” (i.e. the estuary) are much deeper than indicated (MSL -5 m to MSL -9 m according to Barry, 2009). The indicated heights of the spit (some MSL +2.5 m) are relatively low if compared to the heights of the dunes on the same spit north of Goxumbaac and south of Guet Ndar (estimated at some MSL +5 m). It is possible however, that the original land heights have been leveled when the three districts were built.

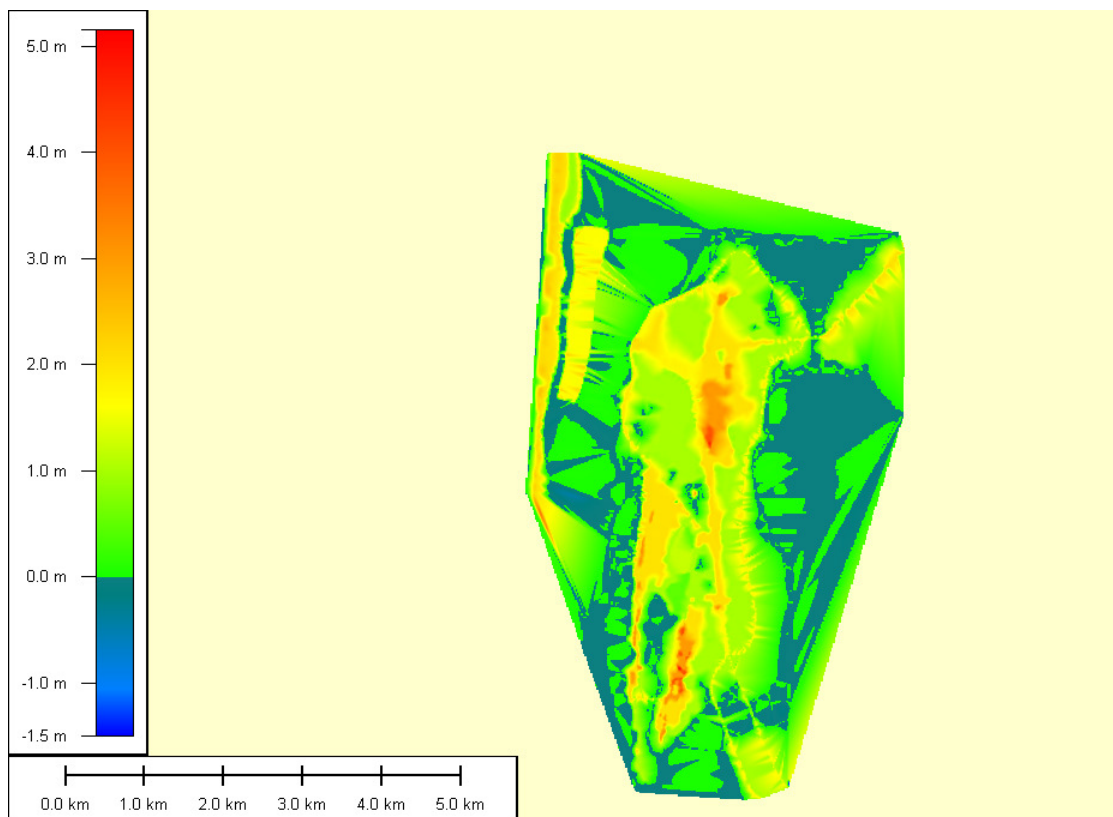


Figure 4.4 Land heights (from Seck, 2010)

The average height of the historic centre (Island of Ndar) is according to these data MSL +1.5 m. The topography of the island of Sor is a bit more complex. The districts of Ndiolofene and Pikine III (south), exhibit heights up to MSL +3 m. Some other districts like Leona and Diaminar are lower: MSL +1 m.

#### Inundation maps

If the data on extreme water levels are combined with the data on topographic heights, so-called inundation maps can be produced. Seck (2010) made these maps for a number of extreme water levels. An example is shown in Figure 4.5 below, which shows the flooded areas, without flood protection, for a water level of MSL +1.5 m. This water level



can statistically occur more than once per year, depending on the river discharge. As explained above, the frequency of this occurrence increases in time when sea level rises.

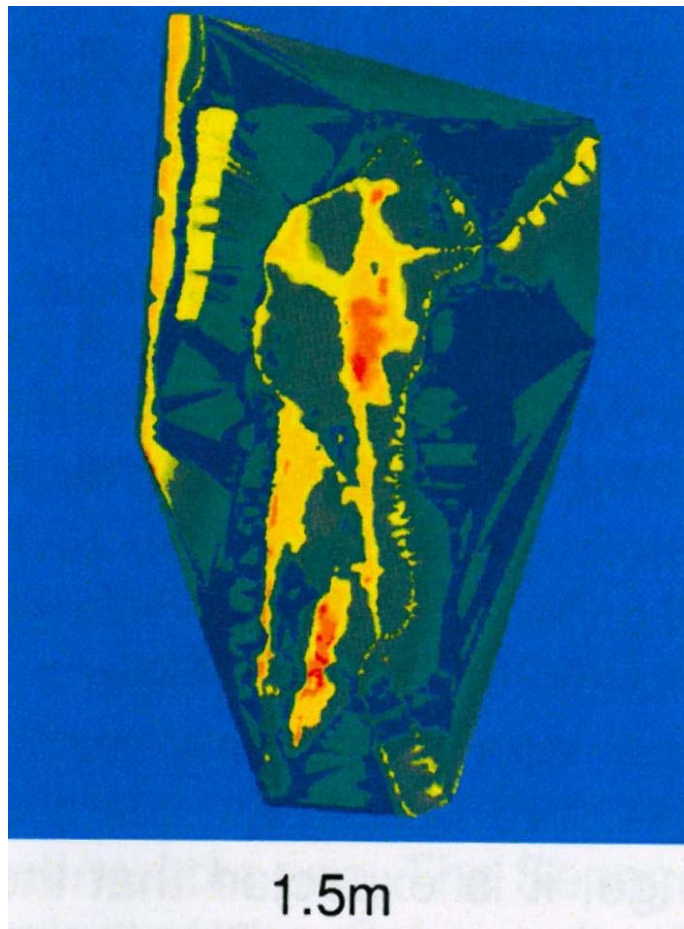


Figure 4.5 Flooded areas for the extreme water level MSL +1.5 m (from Seck, 2010)

The Figure shows that the historic centre under these circumstances “just stays dry”. More extreme water levels, such as MSL +2 m, which is happened only once since 1970, will lead to about 0,5 m water inside the historic centre of St. Louis.

At the same time, with an extreme water level of MSL +1.5 m, the lower areas of the island of Sor will be flooded. In the deeper parts of the island this may even lead to inundation depths of 0.5 m or slightly more. Such depths do not necessarily have to lead to human casualties, but damage to properties will occur and city life will be disrupted.

#### The water defenses

In order to avoid that certain districts are flooded in case of extreme water levels, different attempts have been made by the authorities to install a flood defence system. During the field mission an approximately 0.5 m high concrete flood wall was observed at different locations along the perimeters of the Island of Ndar and the northernmost parts of the island of Sor (see for instance photos 1 and 29 in Appendix B).

Along the rest of the perimeter of the Island of Sor, a dike was built in the Nineties, with heights varying from MSL + 1.5 m to MSL +1.8 m. During the field mission it became evident that the dike is not in a technical state that it can actually avoid any flood. The

dike itself does not enclose all districts, so that even if it would function it would not avoid flooding in all districts of the island of Sor.

#### The flood warning system

Seck (2010) describes the institutional arrangements with regards to local flood management. Both local, regional and national organisations are involved. He concludes that the problem is not a lack of administrative or institutional services but that of an organisational gap leading to a lack of coordination.

Another important issue is the relationship between local and national authorities. The municipality takes care of local planning and construction permits, while all water related issues like flood protection works, are controlled by state departments. This makes an integrated approach towards flood management at least complicated.

In spite of these organisational difficulties, a so-called alert level was defined. This is a certain extreme water level which, when it occurs, results in a flood alert to alarm potentially vulnerable parts of the population. The alert level was defined by the Regional Department of Hydraulics at MSL +1.2 m, which according to the previous data would occur at least several times in each wet season.

### 4.3 Concerns

The major concern of course is that certain parts of the city will be flooded if the water on the short term (days, weeks), exceeds certain levels. In Section 4.2 we estimated that each year, the lowest parts of the island of Sor are likely to be flooded, and that other areas including the historic centre are likely to be flooded with a frequency of less than once a year. Compared to other regions in the world these probabilities are very high. For comparison reasons: before Hurricane Katrina hit the Louisiana coastline in the USA, the flood defense system around new Orleans was designed to protect the city against flood levels with 1/100 y frequency (pre-Katrina era). The Dutch protection levels for low lying areas close to the major rivers (Rhine, Meuse) is in the order of 1/1000 y or less.

Since the urban areas are not located in deep polders, any flood does not necessarily have to result in the loss of human lives. Relatively modest damage will occur in the present situation. But, the potential damage will increase with continuing investments in the urban low-lying areas. In case of a serious flood, daily life will be disrupted and evacuation procedures could become less effective (for instance because of poorly reachable evacuation routes).

### 4.4 Possible strategies

Dealing with flood risks means dealing with two parameters. One is the probability of flooding (in % per year, or number of events per year); the other is the damage in case any flood actually occurs (for instance expressed in terms of monetary losses). Flood risk is often defined as the mathematical product of probability and damage. The unity of flood risk then becomes EUR/y, which is similar to that of flood insurance.

The effect of climate change (sea level rise to be specific) increases the flood risk along its probability axis. However, urban planning and new investments also increase the flood risk along its "consequences-axis".

Strategies to control flood risk should address both components of the flood risk equation. The probability of any flood event can be lowered, for instance with new dikes or floodwalls. Suppose that we reduce the probability with a factor 10. At the same time, urban planning might be boosted because planners and people feel safe behind the new flood protection system. Suppose that the monetarised value of all new properties behind the new flood protection system increases with a factor 100 as a consequence of this urban development. Then, the flood risk still increases with a factor 10, despite the fact that a new protection scheme has been installed.

The above example shows that measures to reduce the flood probability need to take into account both the technical part and the urban planning part. After all, it can be a waste of resources to protect an area which is not likely to be developed in the future. But it can also be a waste of invested capital if a heavily developed area without a proper flood protection scheme, is damaged by floods. The ideal situation is somewhere in between, so: low-enough flood probability for specific urban values or potentials. The level of acceptable flood risk is something for the decision makers to decide.

Specific technical measures which can be considered to reduce the probability of a flood are:

- A closed system of robust surrounding dikes, including measures at each cut-through (for instance where a road crosses a dike). To control the groundwater levels in the dike ring area additional measures, such as pumps will need to be considered too (Chapter 7);
- Temporary or flexible flood protection measures, such as sand bags, mobile flood walls, or multi-panel barriers; or
- Install flood relieve systems to lower or maximize the water level rise. These systems are activated once a certain critical water level is reached. Further increase in water level rise is reduced if water can either flow into low lying retention basins (such as the Three Marigots) or flow out to the ocean via a shortcut over (not through!) the spit.

Specific measures which can be considered to reduce the damage due to any flood can be:

- To build on elevated land;
- To secure evacuation routes and to increase the understanding of people on how to act in times of floods; or
- To design new buildings in such a way that a flood (say up to 0.5 m inundation depth) does not cause any serious damage.

A combination of both types of measures can be considered to make a more balanced approach.



## 5 River mouth dynamics

### 5.1 Introduction

In 2003, heavy rainfall in the drainage basin of the Senegal River alarmed the authorities because it was expected that the water levels at St. Louis would rise above critical levels. It was decided to dig a new outlet for the river water across the spit. This “emergency exit” was some 20 km upstream from the existing river mouth, which was at some 27 km distance from St. Louis.

The dug channel was about 100 m in length (i.e. de width of the spit at that specific location), some 4 m wide and about 1,5 m deep (see left photo below). It grew rapidly in size as can be seen from the right photo which was taken a few months after the opening (both photos obtained from Barry, e.a., 2009).



The new river mouth continued to grow in size and at the same time moved in southward direction. These morphological changes had some serious consequences such as damage on the now exposed inland coast, opposite the new river mouth (Chapter 6).

Moreover, many people started to fear that the new inlet continues to widen and that after some time it may threaten the whole estuary including St. Louis. In this Chapter, we analyse what happened and how morphological changes might develop in the future. In our analysis we gratefully used the results from a study carried out by the US Army Corps of Engineers (Barry, e.a., 2009).

### 5.2 Situation

The rise in water level around the city of St. Louis, in the weeks before the new channel was dug, is shown in Figure 5.1. As can be seen, the water level rose up to +1.9 m (likely above MSL), which must have caused serious flood problems in the city. The channel was dug in the night of 3 to 4 October 2003. The plot clearly shows how fast the water levels at St. Louis dropped (about 1 m in one or two days!).

The rapid drop in water level is explained by the seaward directed flow through the new channel. Due to the erosive forces of this current, the channel scoured rapidly, leading to a relatively wide new inlet. The small channel became a new river mouth, which took over the inlet function from the old river mouth. The old river mouth, located some 20 km further to the South, started to diminish in size and finally closed completely. At that time the new breach had become the only inlet<sup>1</sup>.

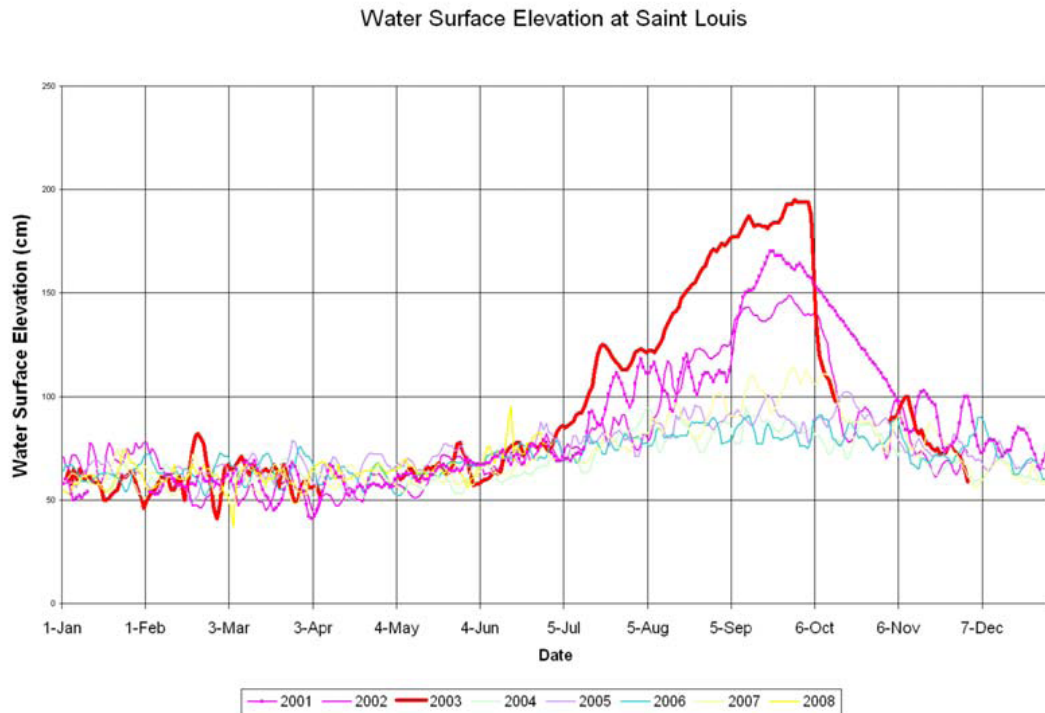


Figure 5.1 Water level changes in the weeks before the new breach was made (source: Ibrahima Diop)

The growth of the inlet can be seen if we compare the situation before and about one year after the channel was dug (Figure 5.2 below, photos obtained from Barry, 2009). The volume of sand from the original spit which seems to have disappeared if both pictures are compared, has been eroded and been deposited for a major portion on the seaside of the new inlet. Breaking waves indicate the presence of these shallow outer bars (visible during the field mission). There are no signs for a built up of an inner delta, but some inward directed sand transport probably also took place.

Barry (2009) writes that the width of the new inlet became 1.4 km in February 2006 and even 2.2 km in February 2009.

The consequences of the new inlet can be summarised as follows:

- The coastline in front of the new inlet retreated due to changing hydraulic conditions (mainly incoming wave action). Unfortunately some 40 houses were destroyed as a result of this local erosion in the town called Doun Baba Dièye (see Chapter 6).

<sup>1</sup> One may also argue that it is an *outlet*, a river mouth, but since tidal flow also plays an important role, we use the term tidal inlet, or *inlet*.

- No (fresh) river water reaches the former estuary south of the new inlet anymore, which increased the salinity of the water (lagoon). This was positive for the salt mining in this region, but most likely negative for the ecosystem (incl the mangroves).
- The tide can more easily penetrate the estuary and reach St. Louis. As shown in Chapter 4, tidal high water levels have indeed increased (Figure 4.1).
- Because river water can more easily flow out into the ocean, the rise in water levels around St. Louis will be less than before the new breach (Figure 5.1). This effect is expected to be larger than the effect of higher tides (viz. a lowering of extreme river flood levels with about 1 m versus an increase in high water of about 0.3 m). This means that the probability of flooding of St. Louis is reduced.



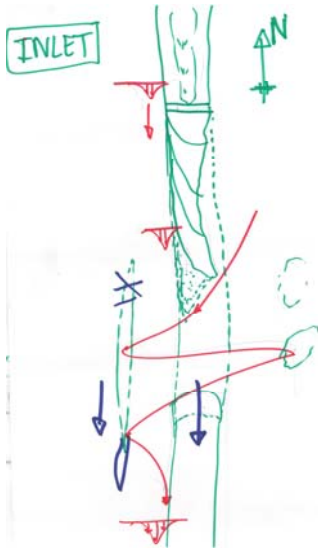
Figure 5.2 Situation before (left) and one year after the opening (right).

The water and sand transport patterns in the new situation are schematically shown below on the next page. After the new channel was dug, it eroded heavily because of high volumes of water flowing in seaward direction. Eroded sand from the spit was deposited offshore, gradually building up the shallow areas on the seaside which are called the outer delta.

Littoral sand transport from the north ( $175,000 \text{ m}^3/\text{y}$  according to the calculations presented in Section 3.1) was not large enough to close the new inlet again. Any littoral sand input was most likely directed in seaward direction too, also building up the outer delta.

After a few days, the seaward flow reduced because of the (significant) lowering of the water levels inside the estuary (1 m according to Figure 5.1). After a few days, also the tide penetrated the (still small) inlet. The combined tide and river flows were however strong enough to continue the scouring process. A few months later the cross-sectional flow area of the new inlet had increased so much that the flow velocities started to decrease. Tidal currents however were still strong because a larger portion of the tidal

basin (the lagoon and the estuary) were filled and emptied through the new inlet. When the maximum inlet flow velocity reduced in time, the littoral sand input from the north into the inlet was no longer flushed out in seaward direction. Instead, littoral sand input was deposited on the northern border of the inlet. The inlet currents however, were still strong enough to increase the cross-sectional flow area of the inlet. This led to erosion both on its northern and southern side, but since deposition of littoral sand occurred on the north side too, the net effect still was that some accretion occurred on the north side of the inlet. On the south side of the inlet only erosion occurred, so the net effect on the south side was a southward retreat of the waterline. These phenomena are sketched below.



The outer delta has an important function today for what is referred to as the by-pass capacity of the inlet. It functions as a kind of “bridge” for incoming sand particles, which after some time reach the down drift coast of the inlet. If the inlet migrates, the outer delta generally follows (see sketch). While the new inlet grew in size and migrated in southward direction, at the same time, the old river mouth closed. Both developments are shown in Figure 5.3 (obtained from Sy, 2010, based on data by Ba e.a.,2007).

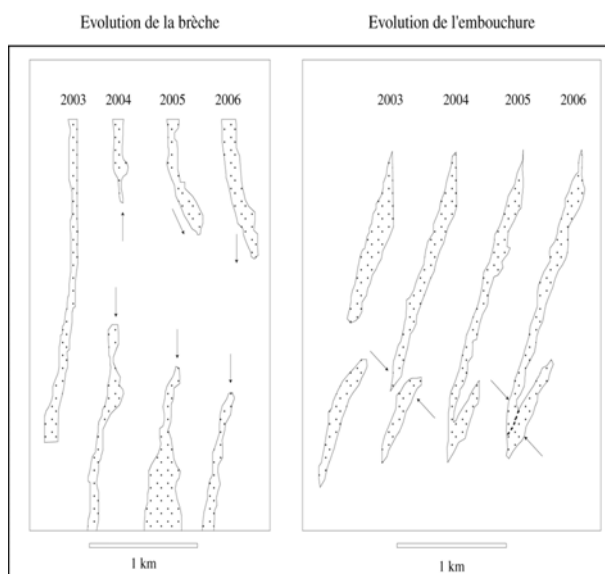


Figure 5.3 Evolution of the old and new inlet (from Sy, 2010)



A field visit to the shoreline just south of the new river mouth, as carried out end of December 2010 by Mrs Marie Dariel, showed clear signs of coastal erosion on the seaside (see photo below). This local coastline erosion is a consequence of the inlet mouth dynamics. A reduced sand supply from the outer delta (sand by-pass principle) to this particular coastal section, in combination with local longshore transport capacity, led to the observed coastline retreat. This type of coastline adjustments are part of the inlet dynamics and do not indicate any overall recession of the whole coastal system.



The location where this photo was taken is indicated in the picture below:



## 5.3 Concerns

During the mission several people expressed their concerns about the behaviour of the new inlet. Below these concerns have been formulated as questions followed by our indicative answers.

### Is the inlet continuing to grow in size?

If the cross-sectional area of the inlet (width and depth) increases, the maximum flow velocity (m/s) reduces too. Lower (maximum) flow velocities have less scouring capacity and as a result, littoral sand input will be deposited and stay inside the inlet (less scour). Because of this deposition, the cross-sectional area will decrease and as an effect of that, the maximum flow velocity will increase again. One can imagine that there is a certain equilibrium between scouring capacity by the inlet currents and sand deposits from littoral drift.

Barry (2009) examined the cross-sectional stability of the inlet. Based on his analysis in which he used Escoffier's theoretical model, it can be concluded that the inlet has reached its equilibrium cross-sectional area (around 3600 m<sup>2</sup>, with maximum inlet depths up to MSL -7 m). Oscillations will take place as a result of changing tides, and in particular, river discharges. Barry estimates that the cross-sectional area can increase to 4600 m<sup>2</sup> in the rainy season combined with spring tide.

So, the answer to the raised question is no. The inlet has reached its maximum size and will only exhibit seasonal fluctuations.

### Is the inlet a threat for the city?

The net effect of the new inlet on the extreme water levels at St. Louis, are positive. So, the new inlet in fact reduced the probability of urban floods, which was the original idea behind digging the channel.

The new inlet will not erode the spit north of it and therefore, will not cause a threat to the city. Instead, as explained below, the new inlet will continue to migrate in southward direction, so away from the city.

### Is the inlet a threat for the area south of it?

The following distinction can be made when dealing with inlet stability:

- Stability of geographical dimensions of the inlet (cross-sectional stability); and
- Stability of the inlet with respect to its location (location stability).

The river mouth has always migrated in southward direction. If the new breach is regarded as just a man-induced acceleration of the natural behaviour, then the new inlet will migrate to the south similar as the historic river mouths. The migration rate of the previous river mouth was estimated to be around 500 m/y (Figure 3.8). The migration of the new breach was estimated to be slower: some 200 m/y based on visual observations during the field trip.

While the new inlet migrates further to the south, it will affect existing functions, such as the nature park which is located just south of the current inlet. The shoreline retreat for instance as this has been experienced at Doun Baba Dièye, will also occur in newly exposed areas south of the present inlet. In terms of spatial development it is therefore better not to locate any new infrastructure in the potentially exposed areas (i.e. in front of the future location of the inlet).

The ecosystem already suffered from the fact that its former estuarine character (including fresh water input) changed into a lagoon system. But, on top of that, erosion can be expected in the areas that will be exposed to the future location of the inlet. It is noted that this also happened numerous times in the past, and one may argue that nature does not need to be protected against itself. In fact, while the inlet migrates to the south, new estuarine ecosystems will develop north of the inlet, which creates new opportunities for nature conservation in due time.

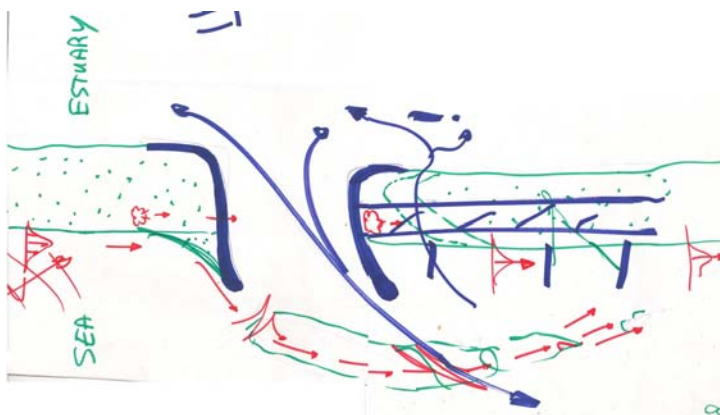
There are no human settlements on the spit south of the inlet. This is possibly due to the fact that this part of the spit has experienced regular breakthroughs in the past, which kept this part of the spit low compared to the northern sections and therefore unsafe for human settlements.

The migration rate is on the order of 200-500 m/y, with a best guess as 300 m/y (Chapter 3). With this southward migration rate figure, one can easily compute when the inlet-related local adaptation can be expected at a certain location.

## 5.4 River mouth fixation

One option which is considered to control the dynamics of the river mouth, is the construction of dams on both sides of the inlet. This so-called jettying of the inlet is sometimes considered in situations where migration can not be allowed (because of expected severe damage), or when certain navigational depths must be maintained (for instance with a sea-connected port inside the estuary).

The sketch below shows how this could look like. Dams need to be constructed on both sides of the inlet, avoiding both sand deposition on one side and erosion on the other side. The dams need to be extended into the estuary to avoid any scouring "from behind" by inlet currents. Depending on the distance between the two dams, a certain depth will develop inside the inlet.



It is not easy to make a design which leads to a stable, safe and low maintenance situation. One of the major concerns deals with the by-pass capacity of the inlet after the inlet fixation. Littoral sand input will continue. Extending the northern jetty with a few hundred m in seaward direction (creating a dam) does not help because of the large obliquity of the incoming waves. And making the dam very long (say 1 km) blocks all littoral drift for a long time, causing serious and uncontrollable down drift erosion.

The littoral sand input from the north will be bridged to the down drift coast (the other side of the inlet) via inlet currents and the outer delta (see sketch). At a certain point, it is possible (but not guaranteed) that the sand continues its littoral journey further to the south. If the "attachment point" of the by-passing sand is at a certain distance from the southern (down drift) jetty, then the risk exists that the spit adjacent to this jetty, will loose sand (local sand transport, but no sand supply). Regular sand nourishment can help to maintain the shoreline, because, if such maintenance is not done, the spit can breach adjacent to the southern jetty. And if that occurs, the whole inlet system will collapse with loss of both jetties (one buried under sand, the other destroyed by scour).

The design of a good functioning inlet jetty system is very complex. And even if the best experts are consulted, nobody can exactly predict the morphological response on such small spatial scales. There will also be the risk of back-scouring and in order to avoid that, regular monitoring and if necessary maintenance, will be required.

The investments to install such a scheme are huge (at least several tens of millions of Euros) and inspection and maintenance costs are estimated to be a few million Euros per year (repair work of the jetties after a storm, dredging of channels which perhaps will be used by oceangoing vessels, nourishments of the down drift beaches). We didn't receive any information on economic drivers that could bare such costs. From an erosion risk point of view, these investments can not be motivated.

Although we didn't made any economic analysis, we have no idea which benefits would actually motivate such large investments. Perhaps the wish to make a new deep water sea port, but no studies on that could be found. From a coastal systems point of view we recommend to be very cautious when considering the jettying of the inlet.

### **An alternative approach**

So, if the river mouth stays on its natural course, then how can we deal with the consequences? These consequences can be summarised as follows:

- Salinisation of the lagoon and its surroundings (see last sketch in Section 3.2), which may lead to lower agricultural productivity and a change in the ecosystem.
- Perhaps deposition of fines (silt) inside the lagoon, which changes the structure of the bed and consequently influences marine life inside the lagoon.
- Erosion of the coastal sections that become exposed when the inlet migrates southwards (with a migration velocity of some 200 m/y).
- Perhaps a change in flow pattern inside the lagoon (compared to the pre-breach period), which may locally lead to shoreline erosion inside the lagoon due to moving tidal channels.

We suggest that a proper Impact Assessment is being carried out so that the consequences of the new river mouth for the ecosystem south of the inlet, will be better understood. Such Impact Assessment should be based on an eco-systems based approach. It would be interesting to do the Impact Assessment for the present position of the river mouth as well as for a few (future) locations further to the south. By closely following the actual southward migration of the inlet, it is possible to estimate when these investigated locations can be expected.

Suppose that according to the Impact Assessment, the river mouth should not be allowed to migrate further to the south than a certain "critical position". For instance because of unacceptable impacts for that location. At the moment that such critical position is soon to be expected, the measure could be to make a new breach at the same location as where the new breach was dug in 2003. History will then repeat itself, but in a controllable manner.

In this way natural dynamics "between limits" can be allowed, keeping the benefits of a river mouth closer to St. Louis (easy access for fishermen and lower flood risks for the city), and at the same time minimising the negative impacts (as summarised above). In practice this approach implies that only a certain stretch of shoreline will be dedicated to accommodate the (future) river mouth. If this is properly incorporated in regional spatial planning, then the natural dynamics of the system does not necessarily need to be a threat or a major problem to the society.

## 6 Coastal erosion

### 6.1 Introduction

Coastal erosion is often experienced as the average retreat of the waterline over a period of time (years). Everything that is crossed by this moving waterline will be lost, except for well-engineered structures which can (at least for a certain period of time) withstand the forces of the sea.

Erosion happens when the balance between sand input and sand output from a certain coastal area becomes negative. A gradient in the longshore sand transport can cause this, but also offshore directed sand transport can be a cause (for instance if one digs a deep hole in front of the beach). Sand extractions from the beach can also result in coastline retreat. Although figures are lacking we don't have the impression that significant volumes of sand are being mined from the beaches.

Serious erosion has been observed on a local scale. On the scale of the whole spit, however, no structural erosion was observed which could lead to a loss of the spit as such. Some older people mentioned during the field mission that the beach used to be much wider when they were young, but no data could be found to support these statements. In view of our analysis in Section 3.2, we don't expect that the whole spit is now eroding or gradually disappearing. It is possible however, that on a time scale of several decades, the beach exhibits a cyclical behaviour with wider and narrower beach widths. Data on such cyclical behaviour could not be found in the studied sources.

Long-term overall retreat of the coastline is not considered to be very likely. There are, however at least two locations where local erosion already caused damage. One is at the wall at Ndar Toute; the other is at Doun Baba Dièye, in front of the current inlet. Both local erosion problems are briefly introduced in the Sections below.

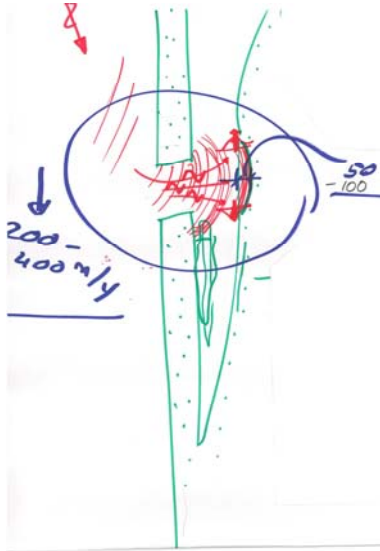
### 6.2 Situation

#### Local coastal erosion at Doun Baba Dièye

The erosion along the island of Doun Baba Dièye is well described in Sy (2010). The erosion is the result of a re-orientation of the shoreline, which is visible on the right picture in Figure 5.2.

Waves penetrate the estuary through the new inlet and reach the beach at the stricken coastal section (see sketch below). The incoming waves generate a littoral drift (similar but much smaller than along the open coast) which carries sand from the centre of the section to both outer sides. The more "circular-shaped" waterline corresponds with the direction of the incoming wave fronts. The erosion may have been aggravated by some increased offshore sand movement, but re-orientation of the local coastline is expected to be the dominant mechanism behind the observed erosion.

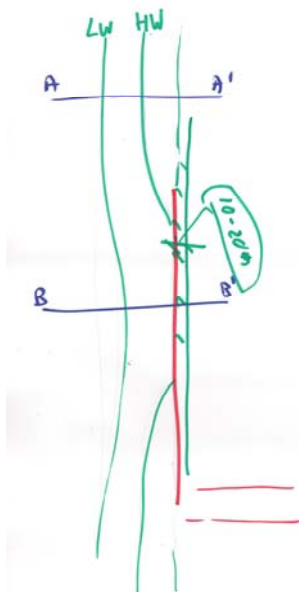
The future locations where similar shoreline changes in the lagoon can be expected basically follow the southward migration of the inlet. The rate of this southward migration was earlier estimated to be around 300 m/y.



#### Shoreline erosion along the Langue de Barbarie

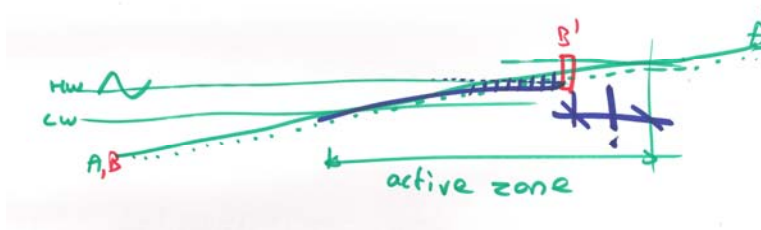
Another location where damage from local erosion was observed, was at Ndar Toute. To be more specific: in front of a wall which is located along a ca 150 m long stretch of coast. This seawall used to be part of a boulevard dating back to colonial times.

During the field trip it appeared that the high water line of the beach bends towards the wall (see sketch below). This could not be seen for the position of the low water line, which seemed more straight. During high tide and stormy weather, waves can reach the seawall and break on it. Since the wall was not engineered to withstand such wave attack, it already got damaged at some locations.



The question is why the HW-line bends towards the wall. One possible explanation is that the wall is located in the so-called dynamic zone of the beach. This is the zone which is influenced by the action of tides and waves. Sand particles in this zone are transported up and down the beach and as long as there are no obstacles, the beach can develop a dynamic equilibrium. But if a hard obstacle, like a wall, prevents the up-beach and down-beach free movement of sand, the balance is disturbed.

Reflected and breaking waves result in increased local turbulence, which leads to scouring in front of the wall. This scour can be recognised from the slightly greater depths in front of the seawall (the HW line bends towards the seawall). If the wall was positioned outside the dynamic zone, then no damage would have occurred. To establish a safe distance requires beach morphology studies, but a 20 m set back is probably a reasonable safe first estimate.



The district of Goxumbaac (north of Ndar Toute) could not be visited during the mission for practical reasons. However, according to the presentation held by the Mayor, Mr. mamadou Abiboulaye Dieye during the Delta Cities Conference in Rotterdam on 30 September 2010, some damage due to local erosion occurred here as well. Without any data however, it is difficult to judge the cause of that damage.



Goxuumbac (December 2010)



In Section 3.2, the importance of washovers for the coastal sand balance was described. In particular, the lower section of the Langue de Barbarie just north of Goxuumbax may cause a general retreat of the shoreline which on the longer term (decades) could indeed be felt and lead to shoreline retreat problems. It may therefore well be possible that the seawall and some of the most seaward located houses have entered the above "active zone", because of this gradual movement of the beach and foreshore (the above photo was taken from the beach at Goxuumbac). So, although sand is not really lost, but basically "re-positioned" in cross-shore direction by such washovers, typical coastal erosion problems can be encountered.

### 6.3 Concerns

During the mission it became evident that many people were worried about the local erosion phenomena. The most important question is if the observed erosion is expected to continue.

The erosion along the coast at Doun Baba Dieye is expected to continue until a new equilibrium orientation of the coastline has been reached. Such a "static equilibrium bay shape" is reached when the new coastline orientation is perpendicular to the incoming annual wave energy flux. Based on the bay shape in the affected section as observed in Figure 5.2, we expect that the erosion is already much less pronounced today. It is possible however, that under specific storm conditions, some extra coastline retreat will take place. A relatively safe distance zone from the present HW line is at least 10 m, to avoid any further damage if such ongoing erosion indeed occurs.

The erosion in front of the wall at Ndar Toute is expected to threaten the stability of the wall. It is reasonable to assume that serious damage will occur during high ocean water levels and heavy storms.

Without any quantitative data on the erosion reported for Goxumbaac, it is difficult to make any predictions, but it is likely that more damage will occur under more extreme storm conditions.

### 6.4 Possible approaches

For the definition of a sound and sustainable coastal defence strategy one must take into account at one hand the net benefits obtained from protecting the coast, and at the other hand the costs for coastal defence measures, while trying to integrate the defence strategy into a wider framework for sustainable development. For such definition, the following three steps can be followed:

1. Analysis of the situation without coastal defence;
2. Analysis of the situation with coastal defence measures; and
3. Integration of best coastal defence measure with other socio-economic functions and potentials.

Coastal engineers have developed all sorts of techniques to slow down or stop coastal erosion (step 2). Well-engineered solutions have in common that they are expensive and require regular maintenance. Poor-engineered solutions in a dynamic environment like we are dealing with here, have in common that they will be destroyed during a severe storm.

Below we summarise a number of coastal engineering measures.

- Groynes (dams perpendicular to the beach). These will not work along the spit because of the large obliquity of the incoming waves.
- Detached breakwaters (dams perpendicular to and at some distance from the beach). These are not only very expensive, but probably not very effective and dangerous in view of the use of the beach by the fishermen.
- Regular beach nourishments. This option helps to widen the beach, but in most cases require regular re-nourishments. Another option is to heighten the lower sections of the Langue de Barbarie so that washover events can no longer occur. The first one to actually deal with would be the lower section just north of Goxuumbac.
- Seawall. These structures in the end destroy the beaches and should not be considered.

In addition to these engineering measures, a set back line can also be considered. This implies that investments are only allowed at a certain safe distance from the dynamic beach zone. In the definition of such setback line, one must consider the long term coastline retreat caused by sea level rise. Damage can be minimised under this strategy, but commitment from all stakeholders is a prerequisite for success.

Whatever solution is followed, communication and local support is of the utmost importance. A large beach nourishment for example, will widen the beach, leading to a more safety of the houses and more space for the fishermen boats. However, this "new land" will most likely be used for new housing as the need for space is very large. Ultimately, this will cause new and even worse coastal erosion problems, once the nourished sand has been transported away by the waves. Clear communication and a strict compliance with the regulations of not-building on the beach, are perhaps even more important than the beach nourishment itself.

The latter is also true for a landward strategy, like the definition of a setback line. If people from the "front-row" are being relocated (and thus being paid to do so), then it must be actively prevented that others start rebuilding the abandoned beach again.

A final remark is about knowing what is happening. Selecting final strategies and solutions require a full understanding of the actual coastal behaviour. And this is still not fully the case. The impact of the washovers, for instance, on the coastline retreat should be better understood and data on coastline changes should be collected on a long time horizon (at least several years). The Gaston Berger University can play an important role in this respect (like field monitoring as being part of the education and research programme of the students).

An interesting site for such detailed monitoring the washover which is located just north of Goxuumbac. If after proper data collection (including what happens during a storm) and analysis it appears that this is indeed a location of significant sand losses, then an adequate measure would be to increase the height of this washover. By doing so, future washovers can be effectively prevented, leading to lesser sand losses from the beach and so less coastline erosion. This can easily be done, by moving the sand from inside (the washover fan) back onto the beach where the dunes are supposed to be. A very preliminary estimate of the volume of sand involved is ca 25,000 m<sup>3</sup>, which is a volume that can potentially be taken care of by local equipment and local contractors. The height and width of these new dunes in this area should be slightly more than the height and width of the undisturbed dunes (see photo in Section 3.2)

## 7 Rainwater

Rainfall stagnation is one of the major flood causes in St. Louis. The problem is in some districts aggravated by poor discharge of household wastewater.

The poor drainage of rainwater is caused by the low drainage capacity and relatively high groundwater levels of the soil. This has its origin in the geological formation of the area.

The specific topography of the Island of Sor is a disadvantage, with its depressions in the districts of Leona and Diaminar (Figure 4.4). Water from the surrounding districts will flow into these depressions, increasing the local problems.

Poor drainage also results from the obstruction of surface water flows at some locations by structures, such as roads, (low) dikes and other structures.

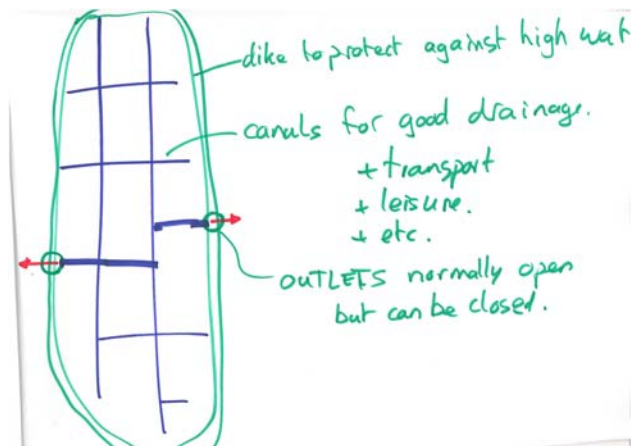
Retention basins, in which excessive amounts of rainwater can temporarily be stored are not present.

Pumping stations were built on the Island of Sor, and one of the pumps was indeed functioning during the field mission (wet season and after a number of days with heavy rainfall). Nevertheless, large parts of Sor were flooded (by rainwater), showing that the capacity of the pumps is not enough to avoid such flooding.

The poor drainage problem seems to be most manifest for the Island of Sor. However, high groundwater tables also cause damage to the basements of colonial buildings in the historic centre (Island of Ndar).

There is a variety of actions which can be considered to increase the drainage capacity of the urban areas or to increase the local retention capacity for rainwater. Possible measures are:

- Dig local depressions in which water from the surrounding neighborhoods can collect and from where water can either be pumped or flow out through an underground system of pipes. Such depressions can serve as local squares, parking places, or gardens under normal conditions.
- A system of canals in which different functions can be combined (transport over water, collection and discharge of excessive rainfall, spatial value, etc.). These drainage canals may flow out into the estuary at one or two locations (see sketch below). Some sort of closure device will be necessary where these canals cross the surrounding dike (remember that the dike is intended to stop the water from the estuary to enter the city if the water levels become too high – Chapter 4). Material from digging the canals can be used to elevate the land on which new buildings can be planned.
- Increase the porosity of the soil by improving the (local) soil characteristics.
- Adjust the topography in such a way that water is not collected in local depressions anymore, but that it can flow to the estuary. This includes the upgrade of specific drainage devices to cross the various structures.



Any choice of an upgraded drainage system must be integrated with the other dimensions of the urban planning process. Plenty of inspiring examples can be found from all over the world, but the most important aspect is that it should fit in the local overall development strategy.

In this respect we would like to point at the unique character of St. Louis, which to a certain extent is similar to other lagoon cities, such as Venice, Italy (St. Louis is sometimes called the "Venice of Africa"). Venice is famous for its waters and the way water has been integrated in the city planning and in city life. Many tourists visit Venice to experience the unique water dimension of the city. St. Louis can choose to do the same, at the same time solving some of their most urgent water-related problems (managing the drainage problem and reducing the flood risk).

If water is approached as an opportunity instead of an enemy that needs to be combated, then St. Louis can make a strong statement to the world, similar as what the Venetians did a long time ago: use the water dimension as a unique selling point and fully integrate it in the short and long term urban planning.



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## Appendix A

### Summary of Activities During the First Mission

# Summary of Activities of the mission 13-18 September 2010

## **Monday 13 September (Dakar)**

01:00 arrival and transfer to Djouff Hotel.

08:30 UN Habitat representative Marie Dariel Scognamillo.

09:00 UNESCO Mrs Isabelle Niang, Regional coordinator for UNESCO's ACCC project.

11:00 Red Cross and Red Crescent. Momodou Lamin Faye, Aram, Maboury Diouf

14:00 Dakar Cheik Anta Diop University. Professor Alioune Kane.

16:00 to 19:30 transfer to St Louis.

## **Tuesday 14 September (St. Louis)**

09:00 Hotel de Ville – UN Habitat mission presentation to representatives from :  
St Louis Municipality – Demba, Soumare, Mme Nba  
DC (Community Development office) – Ali, Antoine Descleves.  
ARD (Regional agency for development) – Mahmoud Diop  
Gaston Berger University – Professor Boubou Sy + 2 students  
Ministry of Hydrology – Adama Ndianor successor to Ibrahim Dioup

10:30 Field trip to Diama Dam and the north strip of the Langue de Barbarie

10:45 Grand Faubourg de Sor. Observation of drainage issue and dike.

13:00 Diama dam. Presentation by the dam manager on the context of the dam and its operation.

15:00 Langue de Barbarie, North point. Observation of the interactions between beach, breach, Atlantic ocean and Senegal river.

17:30 Settlement on Langue de Barbarie. Observation of the cemetery and fish drying beds, elevated view point from the women's association roof terrace. Observation of the interactions between beach, breach, Atlantic ocean and Senegal river. Observation of local adaptation to this environment.

19:30 Close.

## **Wednesday 15 September (St. Louis to Potou)**

09:00 Bountou Ndour. Observation of the estuary and mangrove replanting (clean site managed by Mme Simone N'daw), Observation of salt basins.

Gadga Moubaye. Observation of small cliffs eroded by the waves coming through the breach. Observation of village and agricultural spaces.

Potou. Observation of the former mouth of the estuary, now a lagoon.

16:00 Conseil Regional de St Louis, Prefet Serigne Mbaye.

17:30 ARD, Mahmoud Kane. Informed of projects on the region around St Louis, in particular use of the 3 Marigots site.

20:00 Close

### **Thursday 16 September (St. Louis)**

08:30 DC. Presentation of Urban Development Strategies and vision of St Louis 2030, an African metropolis.

11:00 OMVS library, Mbacke Guaye. Research of maps and data.

14:30 ARCADIS / UN Habitat brainstorm session, preparation of presentation to the municipality.

17:15 Telcon with Agence Francaise de Developpment, Matthieu Vasseur. Discussion about plans for the region of St Louis. Recommend to contact Francois Laurent, project director based at Lausanne, Swiss.

19:30 ARCADIS' Conclusions, draft presentation to UN Habitat.

01:00 Close

### **Friday 17 September (St. Louis and Dakar)**

09:30 Hotel de Ville. Initial conclusion presentation by Rob Steijn and Sarah Beesley to the key stakeholders of St Louis and the region.

11:30 Mission Accomplished!

14:00 transfer to Dakar.

19:00 Dakar.

### **Saturday 18 September**

01:55 Take off to Lisbon



Appendix B  
Photo Impression

## Photo Impression field mission



Photo 1: Road along the northern part of Sor (named Boulevard El Hadj Momar Sourang). Poor water drainage from the road to the estuary. Small scattered damages to the wall.



Photo 2: same position looking to the west with St Louis on the horizon



Photo 3: Between Sor and Khar (towards Richard Toll). People enjoying and using (washing) the water. The road cuts the water in two; a sluice (said to be widened) allows water to flow.



Photo 4: North of Sor. Low lying area where huts and houses are built on top of a foundation of garbage and litter. Most of the area was wet because of rainfall and bad drainage.



Photo 5: On our way to the Dama dam. Low lying land and lots of water everywhere.



Photo 6: The downstream side of the Dama dam. At the time of the visit the discharge was said to be 1600 m<sup>3</sup>/s.





Photo 7: Ship Lock adjacent to the Diama dam.



Photo 8: Upstream side of the Diama dam



Photo 9: On the spit on our way to the new river mouth. On the left side the estuary; the wall on the right side separates the road from the cemetery (which was largely flooded at the time of the mission as a result of heavy rainfall)



Photo 10: Large pools on the way forced us to change cars. Pools caused by rainfall.



Photo 11: Standing close to the new river mouth (inlet) looking northward. The location of the breach was near the vegetated part of the spit, at some 500 distance.



Photo 12: Discussion on the beach just north of the inlet. Waves breaking at some 300 m distance from the shore indicating the presence of an outer bar (ebb-tidal delta).



Photo 13: Almost standing in the inlet looking northward



Photo 14: the locally called "Polish Port" is hardly used by the fishermen because the quays are too high for their boats.



Photo 15: From Guet Ndar looking southwards. The estuary on the left; the ocean on the right with the spit in between. Left from the wall is the cemetery, right of it the fish drying area.



Photo 16: same location, looking northwards



Photo 17: Same location as photos 15 and 16 looking eastward - St. Louis on the back

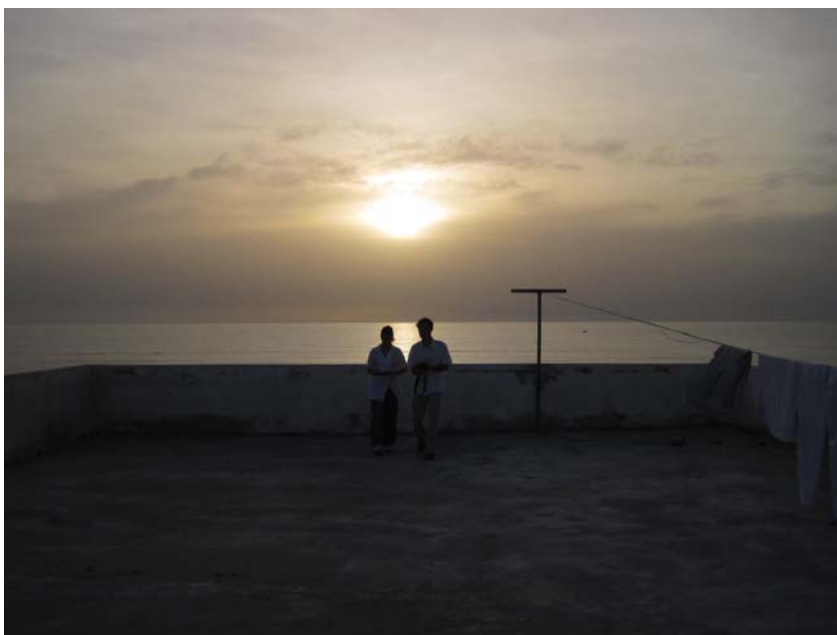


Photo 18: Sarah and Antoine on the roof in Guet Ndar



Photo 19: Seawall at Ndar Toute looking southwards. Narrow beach which disappears at high waters (waves breaking on the seawall causing locally some damage). Wall was said to be part of a boulevard built in colonial times (at least a century ago)



Photo 20: Same location looking northwards



Photo 21: Young coastal morphologists



Photo 22: Idem





Photo 23: On our way to the old river mouth location. Mangroves on the other side of the road. Cut for firewood, but more and more replanted by local communities.



Photo 24: same location, zooming in



Photo 25. Bank erosion in the estuary some 10 km south of the inlet. Looking northward (inlet not visible). Bank erosion was said to be very small (cm/y).



Photo 26: Same location looking southwards



Photo 27: At the location where the old river mouth was (now closed) looking northward.



Photo 28: ARCADIS team standing on the closed old river mouth.



Photo 29: The famous bridge connecting the main island of St. Louis with the island of Sor (bridge was under reconstruction)



Photo 30: Street view of St. Louis.